LEAN SIX SIGMA: BLACK BELT" CERTIFICATION COURSE

COURSE MATERIAL

Asian Institute of Quality Management (AIQM)

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Agenda Sequence

(In Continuation to Green Belt nCourse Contents)

MODULE – 1:

MODULE – 2:

MODULE – 3:

HOME-WORK : SSBB WORK-BOOK ASSIGNMENTS (SECTION)

1. SSBB Quiz 1 (**A-1**)
2. SSBB Quiz 2 (**A-2**)
3. Information on the Quality Gurus (**A-5,6,7**)
4. Business Process Reengineering (**A-13**)
5. SSBB Quiz 3 (**A-3**)
6. SSBB Quiz 4 (**A-4**)
7. Differences between Traditional Management & Six Sigma Management (**A-10**)
8. Yellow Belts: Creating a corporate sense of inclusion (**A-11**)
9. Managing Six Sigma Change Resistance (**A-15**)

DESCRIPTIVE STATISTICS

1. DESCRIPTIVE STATISTICS:

a. Good Process Vs Bad Process:

Leadership thru' Business Excellence

ASCB(E) Accrediting Certifying Bodies UK

Purpose of Data Analysis. → **To understand process – behaviour**

GOOD PROCESS	BAD PROCESS
• Exhibits predictable behavior (output can be predicted) • Is in statistical – control • Called as Stable process • Variation in all the elements (5 Ms & Environment) is consistent. (i.e. variation due to inherent causes only)	• Exhibits unpredictable behavior (output cannot be predicted) • Is statistically out – of – control • Called as Unstable process • Variation in one (or more) of the elements is due to assignable / special cause.

i) Data Analysis helps us to:

(a) Recognize the presence of non-assignable (inherent) causes,

(b) Recognize the presence of assignable (special) causes,

(c) This leads to identification of causes and solutions in the form of continual improvement and breakthrough improvement.

ii) Statistical methods are used for:

- Collection of Data,
- Summarizing the Data,
- Presenting the Data.

This area of statistics is called as Descriptive Statistics.

iii) Statistical Tools used in Descriptive Statistics – Classification:

Data Type:

- Variable
- Attribute
- Count

Analysis Type:

- Trends
- Summaries

b) Data Types:

Variable Data	Attribute Data	Count Type Data
• Measured on a continuous scale e.g. height, weight, time taken for a call, diameter • Example: Time taken to stitch one shirt. *Normal Distribution*	• Classification (Defective/Not Defective) e.g. good/bad, pass/fail, accept/reject or order delivered in 30 mins /not delivered in 30 mins. • Example: 14 defective shirts out of 300 stitched *Binomial Distribution*	• Counting no. of special events e.g. no. of calls in one hour, no., of break downs, no. of accidents, no. of hits on website. • Example: 33 defects in 14 defective shirts *Poisson Distribution*

c) Analysis of Data (Numerical):

Numerical Data can be described by the following 3 properties:

- Measures of Central Tendency
- Measures of Spread

- **Measures of shapes**

i) Measures of Central Tendency:

Most sets of data show a distinct tendency to group or cluster about a central value.

This value is called central tendency. There are 3 measures of central tendency.

MEAN	MEDIAN	MODE
Mean i.e. Average $X = \dfrac{x_1 + x_2 + \text{-------} + x_n}{n}$	Median is mid-value observation after arranging all observations in increasing/decreasing order • If odd no. of readings, median is $\frac{n+1}{2}$ point in the ordered data set e.g. $\frac{25+1}{2}$ i.e. 13th pt • If even no. of readings, median is average of the 2 middle points e.g. 24 readings, Average of 12th & 13th point	Mode is the value in a data set that repeats most frequently
• **Mean is most popularly used as measure for central tendency.** • **However, it gets affected by the**	• **Median is a robust estimate.** • **Not influenced by extreme values (outliers)**	• **Mode is typically used in survey data.** **e.g. rating given by maximum participants for a training feedback**

extreme values.		

Example:

Prices of second hand cars –

US $ 15,800/-
US $ 20,000/-
US $ 17800/-
US $ 12500/-
US $ 33500/- (Outlier)

Mean =

Median =

Exercise:

Calculate Mean, Median, Mode, and Truncated Mean for the following data:

60	**64**
62	**64**
63	**65**

67	**65**
69	**65**
69	**81**

DATA DISTRIBUTION

1. Distribution:

Any large set of measurement forms a **graphical pattern** when the frequency of each measurement is charted.

This graphical pattern is called a **distribution.**

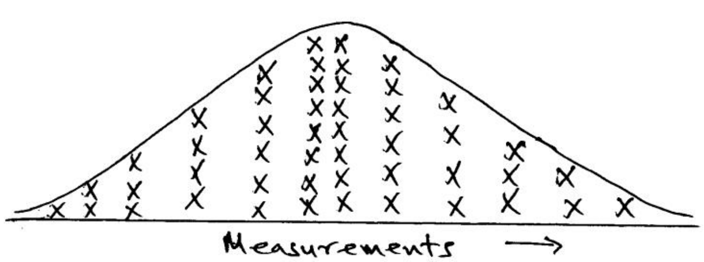


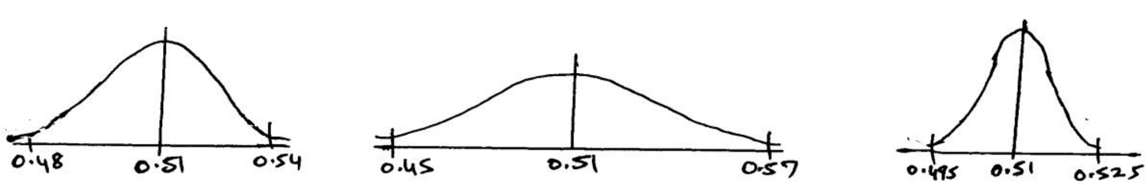
Fig – A: Distribution of day's production

2. Measurable Characteristics of a Distribution:

a. Location i.e. the middle value or average value. e.g. 3 distribution curves may look identical but have middle (average) value at different locations like 0.480, 0.510, 0.540.

b. Spread i.e width of the distribution which shows the variation from one extreme to another.

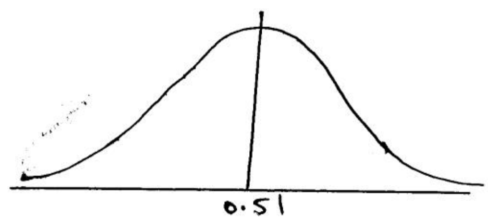
The following distributions have the same average (center) in Fig. B:



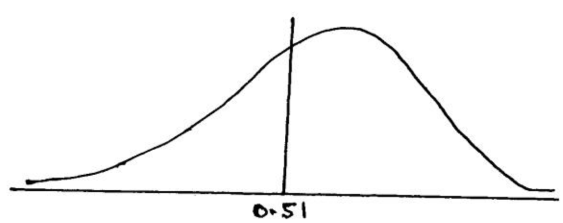
The **narrowest distribution** (iii) represents a process with the least variation.

c. Shape i.e. the way measurements stack up, will lead to different shapes.

The shape generally expected is that of a **normal distribution curve.**



A **skewed shape** implies that there is problem with some of the measurements. When the problem is found and eliminated, the shape will return to a normal pattern.

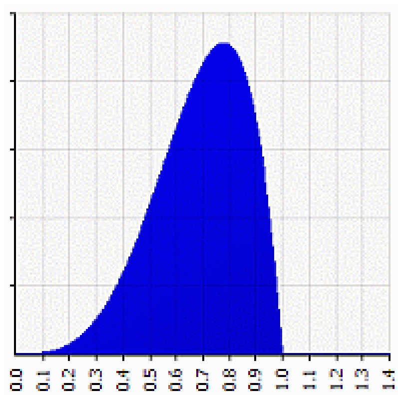


A **bi – modal** distribution is indicated by two peaks i.e. it shows two values of high frequency.

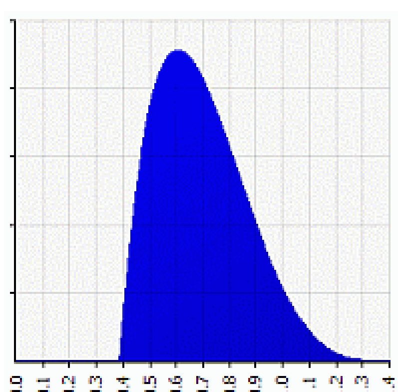
This indicates presence of variation due to an **assignable cause.** Once the cause is removed, the distribution will become normal.

3. SKEWNESS:

If the bulk of the data in a distribution is towards the right and the left tail is longer, we say that the distribution is **skewed left or negatively skewed**.



If the bulk of the data in a distribution is at the left and the right tail is longer, we say that the distribution is **skewed right or positively skewed**.



We say that skewness = 0, when the data are perfectly symmetrical

i.e. left side is mirror image of right side.
(Mean, Median and Mode coincide).

Positive or Negative skewness is an indicator of **assignable cause variation.**
(i.e. Mean, Median, Mode do not coincide).

4. KURTOSIS:

If a distribution is symmetric, the next question is about the central peak: is it high and sharp, or short and broad?

You can get some idea of this from the histogram, but a numerical measure is more precise. The height and sharpness of the peak are measured by a **number called kurtosis.**

- ***Higher values*** **indicate a higher, sharper peak.**
- ***Lower values*** **indicate a lower, less distinct peak.**

The reference standard is a normal distribution, which has a kurtosis of 3.0

Often the kurtosis is presented as: **Excess kurtosis i.e. kurtosis minus 3.0**

E.g: the "kurtosis" reported by Excel / Minitab is actually the excess kurtosis.

Example:

Kurtosis for Process-A = 3.6

Excel / Minitab will report this as excess kurtosis = 0.6

Kurtosis for Process-B = 4.4

Excel / Minitab will report this as excess kurtosis = 1.4

It means that:

* The curve for process-A is **shorter.**

* The curve for process-B is **taller.**

So, the spread (range) is more for process-A compared to process-B.

It means that the **Inherent Cause variation** is more for process-A.

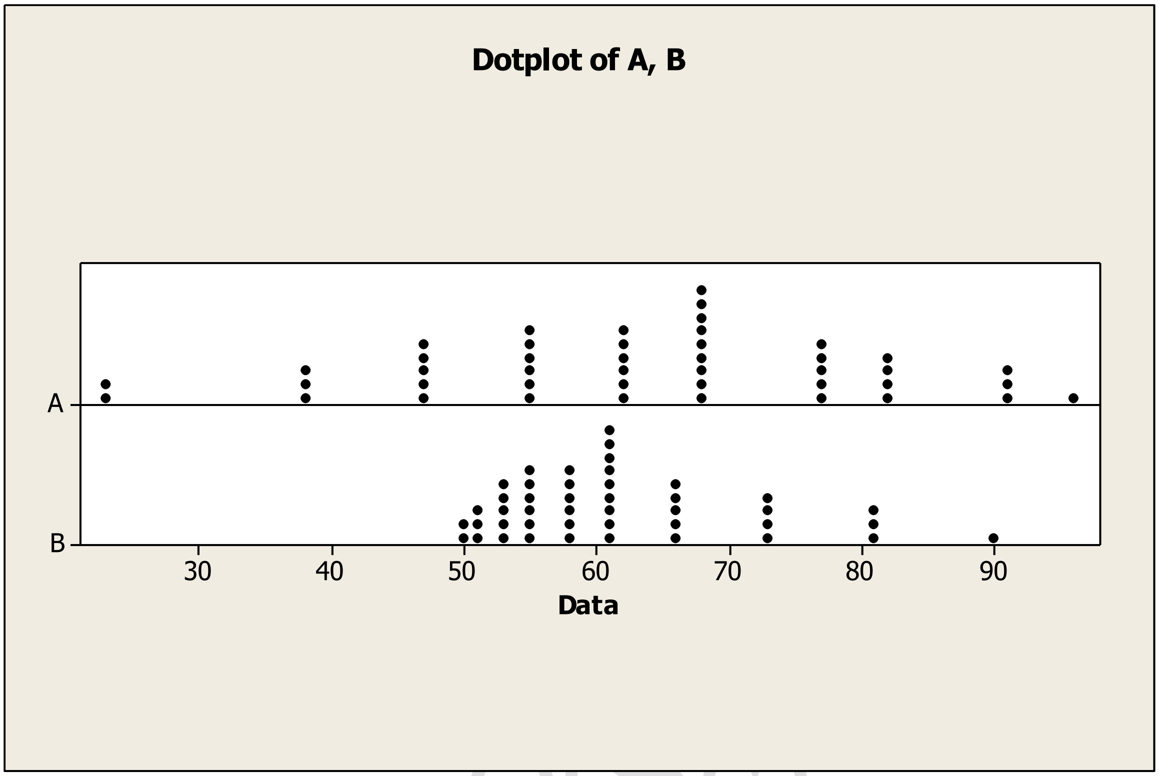
5. DOT PLOT:

Dot Plot is a statistical chart consisting of group of data points plotted on a simple scale, showing the frequency of occurrence of each reading.

Dot plots are one of the simplest plots available, and are suitable for small to moderate sized data sets. They are useful for highlighting clusters and gaps, as well as outliers.

Example:

What conclusions can you draw by comparing the dot plot for School-A and School-B:

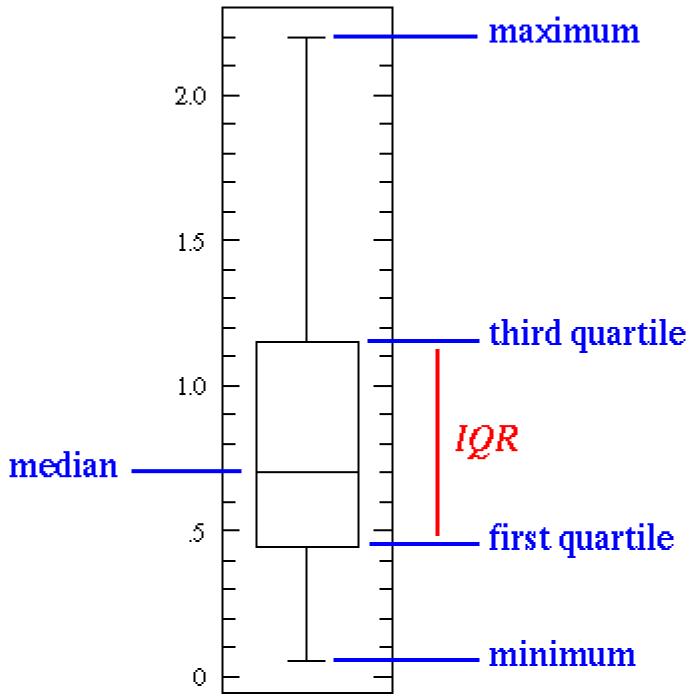


6. BOX AND WHISKER PLOT:

The box and whisker plot is a way of **displaying the distribution of data based on the five number summary: minimum, first quartile, median, third quartile, and maximum.**

In the simplest box plot the central rectangle spans the first quartile to the third quartile (the *inter-Quartile Range* or *IQR*).

A segment inside the rectangle shows the median and "whiskers" above and below the box show the locations of the minimum and maximum.



This simplest possible box plot displays the full range of variation (from min to max), the likely range of variation (the *IQR*), and a typical value (the median).

Exercise: **Draw Box Plot for marks of School-A & School-B below & Interpret.**

Sch-A	Sch-B
23	50
23	50
38	51
38	51
38	51
47	53
47	53
47	53
47	53
47	53
55	55
55	55
55	55
55	55

55	55
55	55
62	58
62	58
62	58
62	58
62	58
62	58
68	61
68	61
68	61
68	61
68	61
68	61
68	61
68	61
68	61
77	66
77	66
77	66
77	66
77	66
82	73
82	73
82	73
82	73
91	81
91	81
91	81
96	90

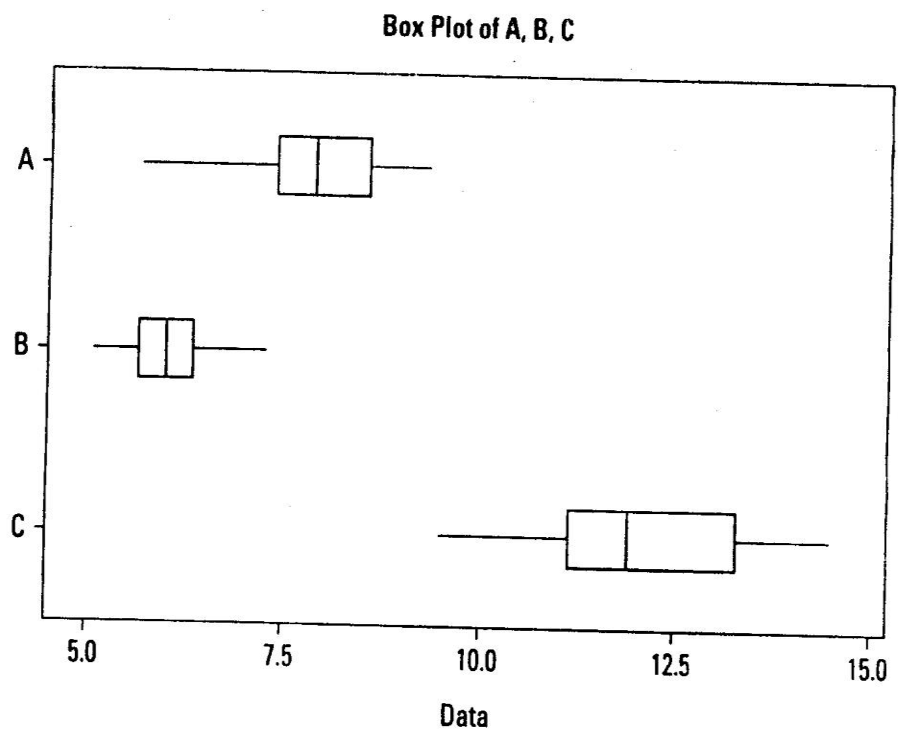
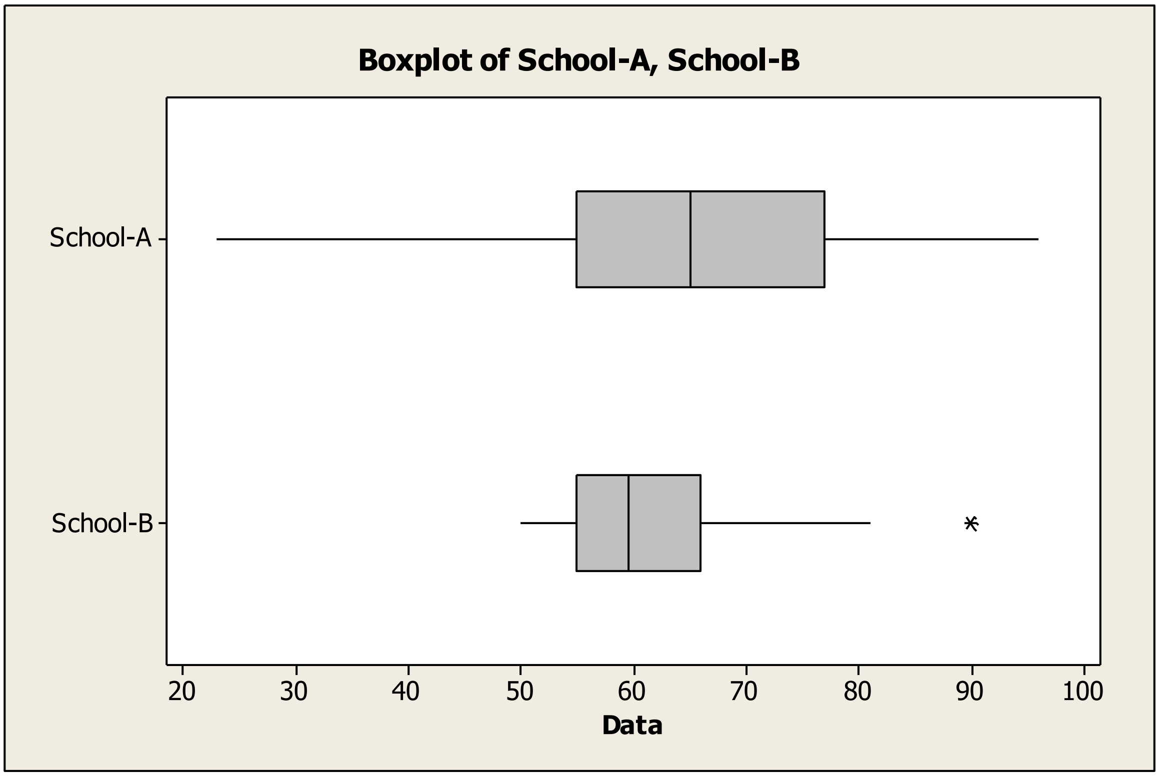


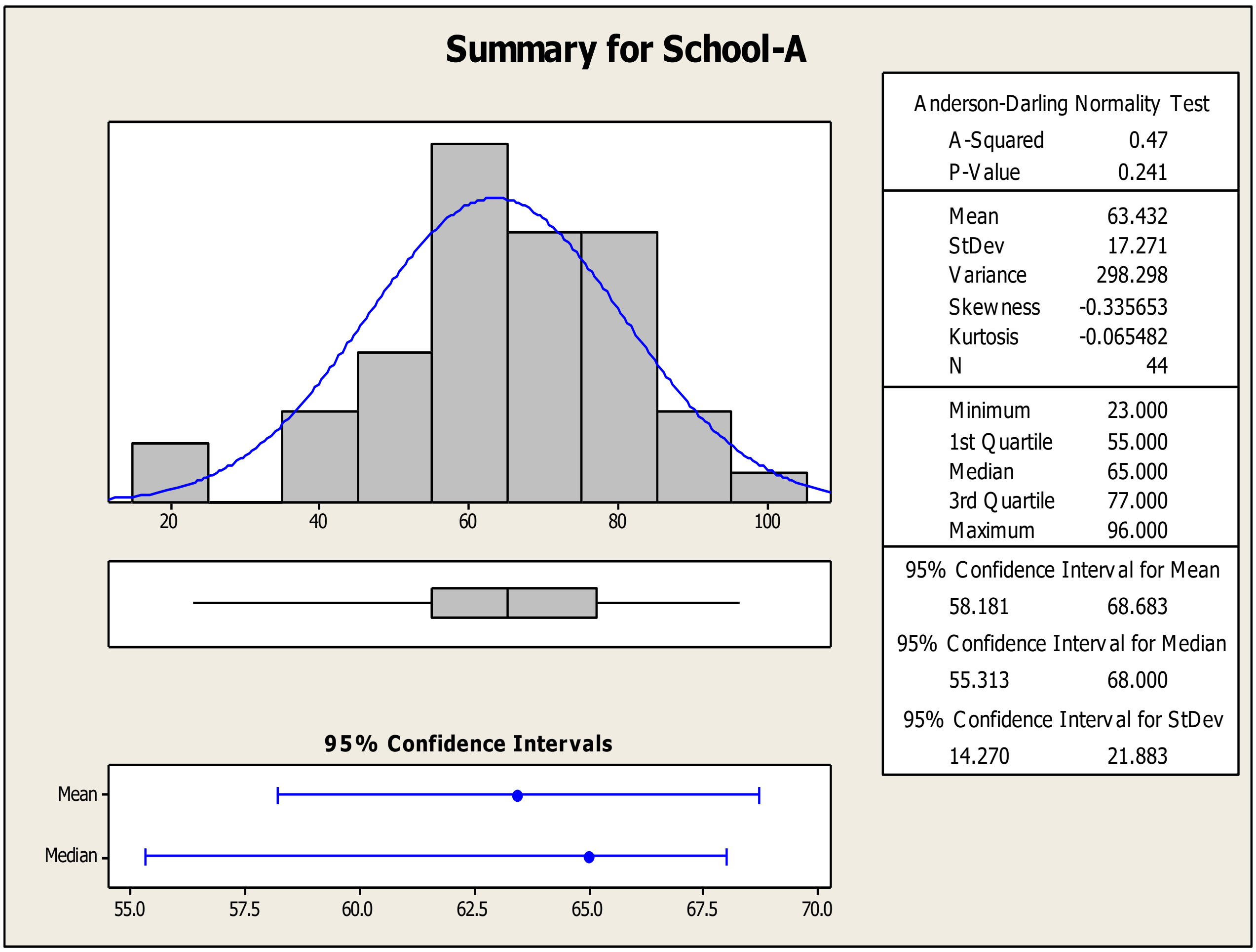
Figure -D Graphical comparison of three variation distributions using box and whisker plots.

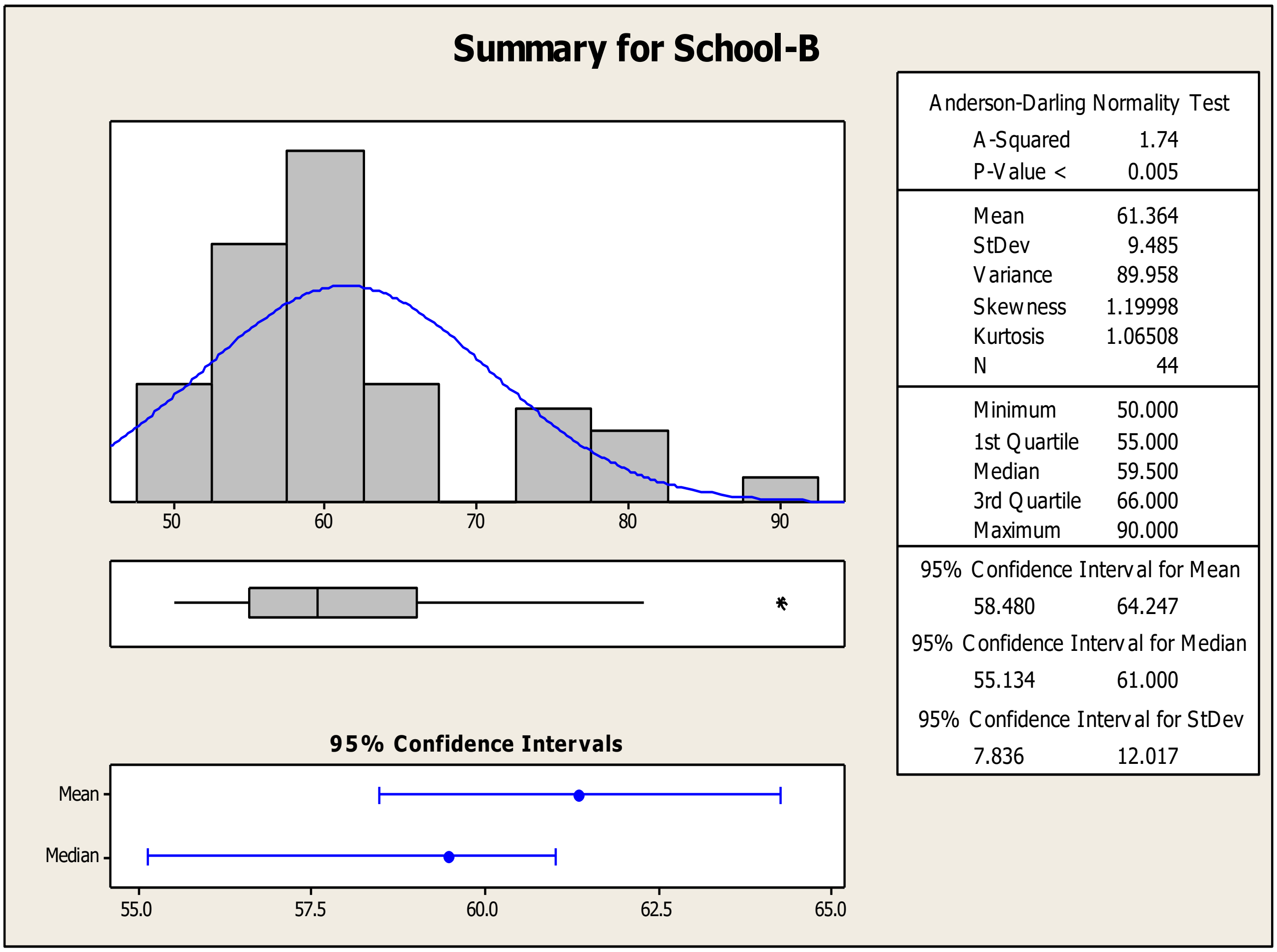
Things to look for in comparative box plots:

- Differences or similarities in location of the median
- Differences or similarities in box widths
- Differences or similarities in whisker-to-whisker spread
- Overlap or gaps between distributions
- Skewed or asymmetrical variation in distributions
- The presence of outliers


Boxplot of School-A, School-B
School-A
School-B
20
30
40
50
60
70
80
90
100
Data

DESCRIPTIVE STATISTICS USING MINITAB





Summary for School-B
Anderson-Darling Normality Test
A-Squared 1.74
P-Value < 0.005
Mean 61.364
StDev 9.485
Variance 89.958
Skewness 1.19998
Kurtosis 1.06508
N 44
Minimum 50.000
1st Quartile 55.000
Median 59.500
3rd Quartile 66.000
Maximum 90.000
95% Confidence Interval for Mean
58.480 64.247
95% Confidence Interval for Median
55.134 61.000
95% Confidence Interval for StDev
7.836 12.017
50
60
70
80
90
95% Confidence Intervals
Mean
Median
55.0
57.5
60.0
62.5
65.0

INFERENTIAL STATISTICS

3. Inferential Statistics:

a) Statistics is the science of handling data. The application of statistical concept involves use of samples to make decisions about a population of measurements.

* A **population** is the set of all possible data values of interest.

* A **sample** is a sub-set (or part) of the population.

* A **random sample** is one in which every element in the population has an equal chance of being chosen.

* A **biased sample** is one in which some elements of the population are more likely to be chosen for the sample than others.

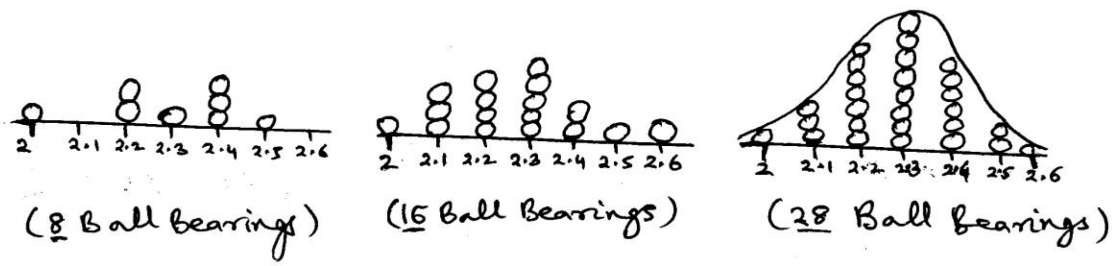
b) Inferential Statistics includes concepts which help us to predict population-values accurately from the sample values. A **biased sample should never be used** to make inferences about a population since it does not represent the population truly.

c) Sample Distribution Vs Population Distribution:

If a random sample is taken from a population and the pieces are stacked according to size, the shape of the developing distribution can take any form.

However as more pieces are added, the shape of the sampled distribution will closely resemble that of the population's distribution.

For example, stacking of ball bearings of diameters ranging from 2 cm to 2.6 cm



The larger the sample (typically n = 100), the more the sample – distribution will resemble the population – distribution. In such a case:

(i) **Center** of the sample – distribution is very close to the center of the population - distribution

(ii) The **spread** of the sample – distribution will be slightly smaller than, but close to, the spread of the population – distribution.

(iii) The shape of the sample – distribution mimics the shape of the population distribution

So, the histogram for the sample is often used to find a standard probability distribution and that pattern is used to calculate the probabilities concerning the population.

For Example:

d) Symbols used for Population – Distribution and Sample – Distribution

Parameter	Population – Distribution	Sample Distribution
i) No. of readings / measurements (x)	N	n(sample size)
ii) Mean	$\mu = \frac{\Sigma x}{N}$	$\bar{x} = \frac{\Sigma x}{n}$
iii) Mean of the sample means	$\bar{\bar{x}}$ (is considered as close to μ) i.e. $\bar{\bar{x}}$ is approx. = μ	------
iv) Range	$x_{max} - x_{min}$	$x_{max} - x_{min}$
v) Standard Deviation	$\sigma = \sqrt{\frac{\Sigma(x-\mu)^2}{N}}$	$s = \sqrt{\frac{\Sigma(x-\bar{x})^2}{n-1}}$ $s = \frac{\bar{R}}{d_2}$ (Shewhart's Formula) $\bar{R} = \frac{(R_1 + R_2 + R_3 - - - - R_n)}{k}$ (d_2 = constant based on sample size) (k = No. of samples)
vi) Variance	$\sigma^2 = \frac{\Sigma(x-\mu)^2}{N}$	$s^2 = \frac{(x-\bar{x})^2}{n-1}$

e) Sampling Distribution of Means:

Suppose you draw a sample of size n=20 from a population of 500 elements, The mean of this sample is $\bar{x}_1$.

You draw another sample of size n=20 from the population of 500 elements, The mean of this sample is $\bar{x}_2$.

You repeat, say 15 times getting $\bar{x}_1$, $\bar{x}_2$ ………………….. upto $\bar{x}_{15}$.

The distribution of these means is called the Sampling Distribution of Means.

The **mean of these means** is the **x(double-bar) = μ (i.e. mean of the population).**

The **standard deviation** of these $\bar{x}_1$, $\bar{x}_2$ ………………….. upto $\bar{x}_{15}$ is called as ***Standard Error*** **S$\bar{x}$**.

S$\bar{x}$ is the **error** which will occur when we try to draw conclusion about population mean from a single-sample mean and is seen to be = $\frac{\sigma}{\sqrt{n}}$

EXERCISE:

9 nos. samples of size '25' each from a population of 500 elements are drawn.

The readings are:

$\bar{x}_1$ = 72
$\bar{x}_2$ = 70
$\bar{x}_3$ = 74
$\bar{x}_4$ = 70
$\bar{x}_5$ = 72
$\bar{x}_6$ = 70
$\bar{x}_7$ = 74
$\bar{x}_8$ = 74
$\bar{x}_9$ = 72

Calculate **mean** of the population.

METHODS FOR DRAWING CONCLUSION FOR POPULATION MEAN:

1. NO. OF SAMPLES – MEAN OF MEANS.

2. CONFIDENCE INTERVAL (C.I.)

*** ONE POPULATION MEAN FROM ONE SAMPLE MEAN.**

3. HYPOTHESIS TESTING:

*** ONE POPULATION MEAN FROM ONE SAMPLE MEAN**

*** TWO POPULATION MEANS FROM TWO SAMPLE MEANS.**

4. ANOVA:

*** THREE OR MORE POPULATION MEANS FROM THREE OR MORE SAMPLE MEANS**

- **CONFIDENCE INTERVALS**
- **HYPOTHESIS TESTING**
- **ANOVA**

CONFIDENCE INTERVALS, HYPOTHESIS TESTING & ANOVA

A. Confidence Intervals: What is interval estimation?

If we take a single sample and find the sample mean $\overline{x}$, this is referred to as the **STATISTIC.**

The population mean μ is called as the **PARAMETER.**

Interval estimation is the use of <u>sample</u> mean $\overline{x}$ to calculate an <u>interval</u> of possible values of the <u>population parameter</u> μ which is not known to us.

Confidence Interval (C.I.) is an <u>interval estimate</u> of the <u>population parameter</u> and is used to indicate the reliability of an estimate.

It is an observed interval (calculated from the observations). In principle, this interval will be different from sample to sample, if the experiment is repeated.

How frequently the observed interval contains the parameter μ is determined by the **CONFIDENCE LEVEL**.

Confidence intervals consist of a range of values (interval) that act as a good estimate of the unknown population parameter. However, in some cases, none of these values may cover the value of the parameter.

The Level of Confidence of the confidence interval indicates the probability that the confidence range captures this true population parameter for a given distribution of samples. It does not describe any single sample.

This value is **represented by a percentage**, so when we say, "we are 95% confident that the true value of “population mean” is in our confidence interval", it means that there is:

* **95 % probability that “population mean” is in this interval,**

and

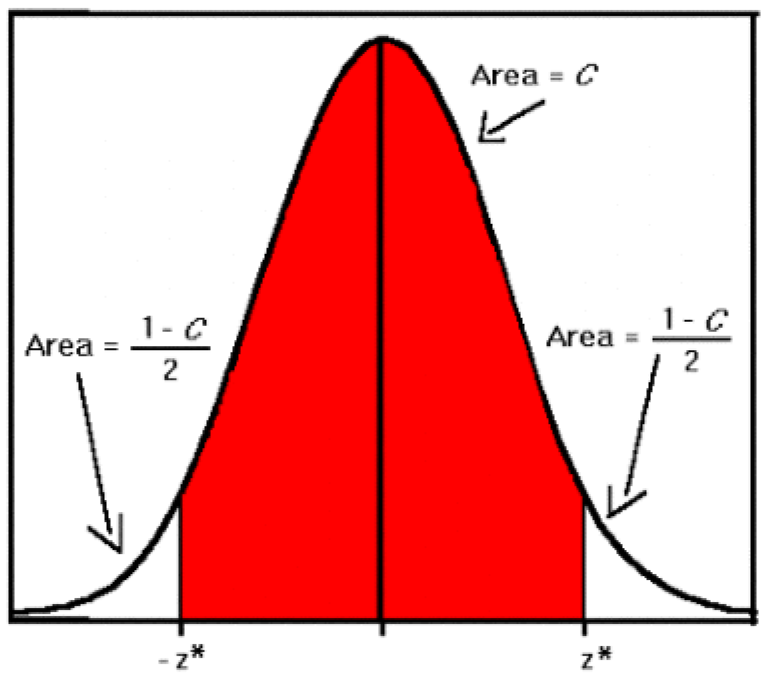
*** 5 % probability that the “population mean” is not in this interval.** This 5% probability also called the **Significance Level α**.

The selection of a confidence level for an interval determines the probability that the confidence interval produced will contain the true parameter value. **Common choices for the Confidence level *C* are 0.90, 0.95, and 0.98.**

These levels correspond to percentages of the area of the normal distribution curve. For example, a 95% confidence interval covers 95% of the normal curve -- **the probability of observing a value outside of this area is less than 0.05, also called as the α –risk.**

Because the normal curve is symmetric, half of the area is in the left tail of the curve, and the other half of the area is in the right tail of the curve. As shown in the diagram to the right, for a confidence interval with level *C*, the area in each tail of the curve corresponds to (1-*C*)/2 i.e. **α / 2**.

For a 95% confidence interval, the area in each tail is equal to 0.05 / 2 = 0.025.



The value **'*z*'** represents that point on the normal distribution, where the area (under the curve) beyond that point i.e. the tail area = **α / 2 %.**

For example, if we talk of C.I. = 95%, then α = 5% and α / 2 = 2.5 % OR 0.025.

From Z-table, we find that corresponding to α / 2 = 2.5 % OR 0.025, z = 1.96.

The Significance level (**α %)** is also called as **'p' value,** i.e. probability that the population mean does not lie under the curve (within the Confidence Interval) – it lies in the tail region.

Z = 1.96 is also referred to as **$Z_{\alpha/2}$** i.e. the value of Z corresponding to **$\alpha / 2 = 2.5\ \%$**

If we refer to Z – table, then **$Z_{\alpha/2}$** corresponds to area under the **right tail,**

$Z_{-\alpha/2}$ corresponds to area under the **left tail.**

Margin of Error E = $Z_{\alpha/2}$ x $\frac{\sigma}{\sqrt{n}}$.

Exercise -1:

$\overline{x}$ = 0.3

N (Population Size) = 1000

n (Sample Size) = 49

σ (s) = 0.05

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Then the end points of the confidence interval (**C.I.**) = $\overline{x}$ **$\pm$ E**

For α = 5 %, $Z_{\alpha/2}$ = 1.96,

C.I. = $\overline{x}$ $\pm$ E = 0.3 $\pm$ E

= 0.3 $\pm$ $Z_{\alpha/2}$ x $\frac{\sigma}{\sqrt{n}}$

= 0.3 $\pm$ 1.96 x 0.05 / sq. rt. of 49

= 0.3 $\pm$ 1.96 x 0.05 / 7

= 0.3 $\pm$ 0.014

C.I. = 0.286 to 0.314

In other words, the 95 % C.I. is 0.286 to 0.314.

i.e. We can say with **95% Confidence** that the population mean μ lies between **0.286 to 0.314.**

Exercise - 2: For the above exercise,

a) What will be the confidence interval for **α = 10 %?**

b) What will be the confidence interval for **α = 2 %?**

Exercise - 3:

A supplier **claims** that the average length (per part) of a shipment of 500 parts is **1.84 m, i.e.** μ **= 1.84**

The customer chooses a random sample of **n = 64 parts.**

The sample mean $\overline{x}$ **= 1.88**

Standard deviation **s = 0.03**

Check the claim for 95% confidence interval for the population mean.

95 % C.I. will be:

$= 1.88 \pm Z_{\alpha/2} \times \frac{\sigma}{\sqrt{n}}$

$= 1.88 \pm Z \times (0.03) / 8$

$= 1.88 \pm 1.96 \times 0.03 / 8$

$= 1.88 \pm 0.007$

95 % C.I. is between 1.887 and 1.873.

= 1.887 and 1.873

∴ the customer can state with 95 % confidence that the population mean μ is between 1.873 & 1.887

i.e. we can say with 95 % confidence that the vendor's claim is not correct.

SAMPLE SIZE:

- If we can decide margin of error and confidence level in advance, we can calculate the required **sample size:**

Suppose in above example we fix margin of error as 0.008 and 95 % confidence interval, then,

Since $E = Z_{\alpha/2} \times \frac{\sigma}{\sqrt{n}}$

$$\therefore \sqrt{n} = Z_{\alpha/2} \times \frac{\sigma}{E} = \frac{1.96 \times 0.03}{0.008}$$

$$\therefore \sqrt{n} = 7.35$$

or n = 54.02 i.e. sample size should be = 55

- **Generally,** for sample size n ≥ 30, we can assume approximate value of sample standard deviation as = value of population standard deviation, **provided** the population is a normal distribution.

Exercise - 4:

A fruit juice manufacturer claims on the tetrapak label that it contains **500ml** of juice.

To test the validity of this claim, the food inspection team randomly selects a sample of **36 nos.** tetrapaks. They find an average content of **498.5 ml** with a standard deviation of **6 ml. Test at alpha = 0.05** to check the claim.

Exercise - 5:

A supplier **claims** that the average length (per part) of a shipment of 500 parts is **1.84 m, i.e.** μ **= 1.84.**

The customer chooses a random sample of **n = 25 parts.**

The sample mean $\overline{x}$ **= 1.88**

Standard deviation **s = 0.03.**

Check the claim for **90% confidence interval** for the population mean.

Exercise - 6:

The problem-resolution team claims that average time taken to resolve a complaint is 2.0 hours (μ = 2.0).

As per data collected, $\overline{x}$ = 2.20 hours, **n = 49,** s = 0.6

a) Check the claim for **95% confidence interval** for the population mean.

b) As per data collected, $\overline{x}$ = 2.15 hours, **n = 24**, s = 0.5
Check the claim for 95% confidence interval for the population mean.

Exercise - 7:

The operations team in a call centre claims that average time taken to handle a call (μ = 2.8 mins).

As per data collected, $\overline{x}$ = 3.2 mins, **n = 64,** s = 0.4

a) Check the claim for **95% confidence interval** for the population mean.

b) As per data collected, $\overline{x}$ = 3.3 mins, **n = 28**, s = 0.38
Check the claim for **95% confidence interval** for the population mean.

- For **smaller sample (n < 30),** if the population is a normal distribution the confidence intervals are calculated from **t – table,** using

$$\bar{X} \pm t_{\alpha/2} \times \frac{s}{\sqrt{n}}$$

(here value of "t" is taken from the **t – table** corresponding to the degrees of freedoms "n-1").

- **Example:**

  A stable process has been producing a part with a dia = 1.575 cm. A new cutting tool is installed. Will the diameter change?

  We take random sample of size n = 12 and find $\bar{X}$ = 1.577, s = 0.0008.

  Assuming that the diameters are normally distributed, the 95 % confidence interval = $\bar{X} \pm t_{\alpha/2} \times \frac{s}{\sqrt{n}}$

  (Here df = 12 – 1= 11)

  Then 95 % confidence interval is $= 1.577 \pm t_{0.025} \times \frac{0.0008}{\sqrt{12}}$

= 1.577 ± 2.20 x 0.00023

= 1.577 ± 0.0005

= 1.5775, 1.5765

Since $\bar{X}$ = 1.575 is not in this interval, we can be 95 % confident that the mean has changed.

2. One Sample Z – test or t – test for population mean:

STEPS FOR HYPOTHESIS TESTING:

a) Conditions:

i) Population is normally distributed or n >30

ii) σ known (if σ is not known, we use "s" with **t – table)**

b) Null Hypothesis H_o : $\mu = \mu_o$

Alternative Hypothesis H_a : $\mu \neq \mu_o$, $\mu < \mu_o$, $\mu > \mu_o$

- When H_a has "$\neq$" sign, it is a **two – tail test**
- When H_a has "<" sign, it is a **left – tail test**
- When H_a has ">" sign, it is a **right – tail test**

c) Calculate the α value (also called as **P – value)**

B. Hypothesis Testing:

To conduct a Hypothesis Test, usually some theory has been put forward, either because it is **believed to be true or because it is to be used as a basis for argument, but has not been proved**.

E.g. claiming that a new drug is better than the current drug.

In each problem, the issue is simplified into two competing claims / hypotheses between which we have a choice**: the null hypothesis, denoted H_0, against the alternative hypothesis, denoted H_A.**

The experiment has been carried out to disprove or reject a particular hypothesis, i.e. the null hypothesis - it cannot be rejected unless the evidence against it is sufficiently strong.

E.g:

H_0: There is no difference between the new drug and the current drug (Normally, this is opposite to what the data shows).

H_A: There is a difference OR the new drug is better than the current one.

Analogy – Courtroom trial:

A hypothesis test is like a criminal trial: **Defendant is considered "not guilty" as long as his guilt is not proven**. The prosecutor tries to prove the guilt of the defendant. Only when there is enough evidence the defendant is convicted. We begin with two **hypotheses:**

H_0: Defendant is not guilty (As per the data, we believe that he is guilty).

H_A: Defendant is guilty.

d) Determine the Critical Values.

For a two – tail test	**For left tail test**	**For right tail test**
• Use Z – table • Find the value that has an area of $\alpha/2$ to its right. • This value and its negative are the critical value. • The **reject region** is the area to the **right** of the +ve value and the area to the **left** of the –ve value.	• Use Z – table • Find the value that has an area of α to its right. • The –ve of this value is the critical value. • The **reject region** is the area to the left of the –ve value.	• Use Z – table • Find the value that has an area of α to its right. • The reject region is the area to the right of the +ve value.

Note: In cases where sample size is < 30, use t – table. The steps are same as for Z – test, except that we use t – table by using degrees of freedom (n-1).

In this case the test statistic (t) = $(\bar{x} - \mu_0) \times \frac{\sqrt{n}}{s}$

e) Calculate the test statistic using

$$Z = (\bar{X} - \mu_0) \times \frac{\sqrt{n}}{\sigma}$$

$$\text{or } t = (\bar{X} - \mu_0) \times \frac{\sqrt{n}}{s}$$

f) If the test statistic is in the **reject region,** reject H_o

(Otherwise do not reject H_o)

Example – 1:

A vendor claims that average weight per part in a shipment of 500 parts is 1.84 kg

The customer randomly chooses 64 parts and finds $\bar{X}$ = 1.88.

Suppose σ is known to be = 0.03

If the customer wants to be 95 % confident that the supplier's claim is incorrect before rejecting the lot, then:

a) i) The distribution is normal

ii) Sample size > 30

iii) σ is known

b) $H_o : \mu = 1.84$

$H_a : \mu \neq 1.84$

c) This is a 2 – tail test, so $\alpha/2 = 0.025$

$\therefore$ Critical values are the z value that has 0.025 its right & 0.025 to its left.

These values are 1.96 and – 1.96 for = 0.025

d) So, $z = (1.88 - 1.84) \times \sqrt{64} \,/\, 0.03 = 10.7$

e) Since 10.7 is > 1.96 (i.e. in the reject region), we **reject H_o**

Conclusion: At 0.05 significance level, the vendor's claim that average weight = 1.84 is **false**

Example – 2:

In above sample suppose sample size = 16 and we do not have σ (standard deviation) of population.

Then, we calculate s for the sample of 16 parts. If customer wants to be 95 % confident that supplier's claim is false:

a) i) Distribution is normal, $n < 30$

ii) We use **t – table** and assume $s = \sigma$

b) $H_o : \mu = 1.84$

$H_a : \mu \neq 1.84$

This is a 2 – **tail** test.

c) $\alpha = 0.05$, df = 16 – 1 = 15

d) So, $t_{0.025} = 2.131$

It means the **reject region** is right of 2.131 and left of – 2.131

e) $t = (\bar{x} - \mu_o) \times \frac{\sqrt{n}}{s}$

$= (1.88 - 1.84) \times \frac{\sqrt{16}}{0.03}$

$= 5.33$

f) Since, 5.33 is in the reject region,

H$_o$ is rejected.

∴ the vendor's claim that the average weight is 1.84 **is false** at a significance level of 0.05

Example – 3:

A cut-off saw has been producing parts with a mean length of 4.125 cm.

A new blade is installed.

We want to know whether the mean length of each part has been reduced.

- We select a random sample of 20 (Measure length of each part and find):

  $\bar{X} = 4.123$

  $s = 0.008$

- Using a significance level of 0.10, determine whether the mean length has reduced.

- $H_o : \mu = 4.125$

  $H_a : \mu < 4.125$

This is a **left tail test**

- Since $\alpha = 0.10$,

  the +ve critical value for df = 19 is 1.328
- As this is a left tail test, the critical value is – 1.328
- $t = 4.123 - 4.125 \times \frac{\sqrt{20}}{0.008} = -1.1$

  Since –1.1 is not in the reject region, H_o **is not rejected.**

  (i.e. at 0.10 significance level, the data does not indicate that average length has decreased.)

3. Testing for two population means:

Suppose we have a doubt whether the cycle times for product A assemblies are different from product B assemblies.

A 20-piece sample of product A assemblies is randomly collected, we calculate

$\overline{X}_1 = 10.5$, s = 2.2

Another 10-piece sample of product B is collected, we calculate

$\overline{X}_2 = 11.9$, s = 2.5

Based on these samples, are **the average of the two products different?**

It is obvious that the sample averages (10.5 and 11.9) are different.

However, if we take a second sample of product A, its average is likely to be different from the first sample. So **how much difference in the samples is to** be expected from product A ?

A ***hypothesis test*** can be performed to test whether the averages of product A and product B are identical.

This hypothesis test on the mean of two samples tests the **null hypothesis** that the mean of population A is equal to the mean of population B. (i.e. $\mu_1 = \mu_2$).

i.e. $H_o : \mu_1 = \mu_2$

$H_a : \mu_1 \neq \mu_2$

(This is a **2 – tail test).**

A pooled standard deviation (Variance) is calculated as follows:

$$S_p^2 = \frac{(n_1 - 1)\, S_1^2 + (n_2 - 1)\, S_2^2}{(n_1 + n_2 - 2)}$$

$$\therefore S_p^2 = 5.29$$

$$\text{or } S_p = 2.3$$

$$\text{So, } t_o = \frac{\bar{X}_1 - \bar{X}_2}{S_p \times \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} = \frac{10.5 - 11.9}{2.3 \times \sqrt{0.15}}$$

$$= -1.573$$

For a significance level of 0.1, $\alpha/2 = 0.05$

For df = 28, the t – statistic's critical value from t – table = + 1.701 and – 1.701

Here, t_o > t critical so it is outside the reject region.

So, We cannot reject the null hypothesis.

EXERCISES ON HYPOTHESIS TESTING:

1. Exercise: Comparing Test Scores between two trainers:

A	B	t-Test: Two-Sample Assuming Unequal Variances		
125	112			
115	98		*A*	*B*
119	109	**Mean**	**112.8889**	**98.44444**
85	96	Variance	196.6111	243.5278
97	77	Observations	9	9
107	70	Hypothesized Mean Difference	0	
125	114	df	16	
125	100	**t Stat**	**2.06551**	
118	110	**P(T<=t)** one tail	0.027733	
		t Critical one-tail	**1.745884**	
Av.112	Av.98	**P(T<=t)** two-tail	0.055467	
		t Critical two-tail	**2.119905**	

2. Exercise: Comparing Sales of Retail Outlets (Before & After Campaign):

Before	After
240	270
225	245
250	260
280	290
200	190
150	160
165	160
100	130
130	135
170	175
Av. 191.0	Av. 201.5

t-Test: Paired Two Sample for Means

	Before	*After*
Mean	**191**	**201.5**
Variance	3315.55556	3516.94444
Observations	10	10
Pearson Correlation	0.97485134	
Hypothesized Mean Difference	0	
df	9	
t Stat	**-2.5119745**	
P(T<=t) one-tail	0.01660151	
t Critical one-tail	**1.83311292**	
P(T<=t) two-tail	0.03320301	
t Critical two-tail	**2.26215716**	

3. Exercise: Time Taken for Issue of Employment Visa Country 'A' and 'B'

COUNTRY "A"	COUNTRY "B"
25	29
25	29
31	29
31	33
31	33
37	39
38	39
43	44
43	45
43	48
43	49
47	49
47	58
53	58
55	58
58	58
59	58
61	62
61	62
68	63
68	66
70	74
71	77
71	77
72	83
74	83
74	89
76	89
79	95
81	95

z-Test: Two Sample for Means

	COUNTRY "A"	*COUNTRY "B"*
Mean	**54.5**	**59.03**
Known Variance	300	417
Observations	30	30
Hypothesized Mean Difference	0	
z	**-0.927296676**	
P(Z<=z) one-tail	0.17688626	
z Critical one-tail	**1.644853627**	
P(Z<=z) two-tail	0.35377252	
z Critical two-tail	**1.959963985**	

4. ANOVA -Testing for More than Two Populations means:

Where there are more than two populations to compare, **an ANOVA, (i.e. analysis of variance)** is used.

ANOVA provides a means of comparing the variation **within each subset (or treatment)** of data to the variation **between the different subsets** of data. The between subset variation is a reflection of the possible differences between the subset averages**.**

The within subset variation, for each subset, is a reflection of the inherent variation observed when sampling from the subset repeatedly.

The null hypothesis tested by the ANOVA is that all the subset averages are equal $\mu 1 = \mu 2 = \mu 3$.

The F statistic is used to compare the mean square treatment (the average between subset variation) with the mean square error (the sum of squares of the residuals).

The ANOVA procedure is typically used to determine whether the data from three or more populations formed by the treatment options from a single factor designed experiment indicate that the population means are different.

Example: Impact of Training Hours on Productivity:

	TEAM -1		TEAM – 2		TEAM - 3	
	100 Hours Training		150 Hours Training		200 Hours Training	
WEEK	Productivity Per week (%)	y-i Sq.	Productivity Per week (%)	y-i Sq.	Productivity Per week (%)	y-i Sq.
1	91	8281	92	8464	94	8836
2	93	8649	94	8836	92	8464
3	89	7921	90	8100	91	8281
4	90	8100	93	8649	95	9025
T-1= 363		32951	T-2 = 369	34049	T-3 = 372	34606
Mean =90.75			Mean =92.25		Mean =93.00	

Question:

Can we say with 95% Confidence that productivity does not change much between change of training hours from 100 – 150 – 200.

The procedure:

1. Ho : $\mu_1 = \mu_2 = \mu_3$

   Ha : All the means are not equal.

2. Construct the ANOVA table:

Source of Variation	Sum of Square	Degree of Freedom	Mean Squares	F – statistic
Between treatment	SS_B	$k - 1$	$MS_B = SS_B \div (k - 1)$	$F = MS_B \div MS_W$
Within treatment	SS_W	$N - k$	$MS_W = SS_W \div (N - k)$	
Total	SS_T	$N - 1$		

Where

N = number of readings

n = number of readings per level (or treatment)

k = number of levels (or treatments)

T = grand total of readings $\sum y_i = \sum T_i$

C = correction factor = $T^2 \div N$

y_i's = individual measurement

SS_T = Sum of Squares Total = $\Sigma y_i^2 - C$

SS_B = Sum of Squares Between Treatments = $(\Sigma T_i^2 / n) - C$

SS_W = Sum of Squares Within Treatment = SS_T - SS_B

The basic idea here is to **determine whether the variation caused by the factor is a sufficiently large multiple of the experimental error to reject the null hypothesis. The F – statistic measures that multiple.**

4. The test statistic is the F-value as defined in the table.

5. Find the critical value in an F table using k – 1 as the numerator degrees of freedom and (N-k) as the denominator degrees of freedom.

6. Determine whether the null hypothesis should be rejected.

Example: A process can be run at 180° C, 200° or 220° C. Does the temperature significantly affect the moisture content?

To answer the question, four batches were run at each of the temperatures. The twelve runs were executed in random order. the results:

Temperature

180°C	200°C	220°C
10.8	11.4	14.3
10.4	11.9	12.6
11.2	11.6	13.0
9.9	12.0	14.2

The entries in the table will be referred to as **y-values = moisture content values** (in percent H_20).

The hypothesis test:

1. $H_0 : \mu_1 = \mu_2 = \mu_3$

   H_1 : All the means are not equal.

2. $\alpha = 0.10$

   (Since this is 2 – tail test, we will refer to table for $\alpha/2 = 0.05$

   i.e. $F_{0.095}$ table)

3. Construct the table. The first step is to find the total and average in each column:

	Temperature	
180° C	**200° C**	**220° C**
10.8	11.4	14.3
10.4	11.9	12.6
11.2	11.6	13.0
9.9	12.0	14.2
T1 = 42.3	T2 = 46.9	T3 = 54.1
$\overline{y1}$ = 10.575	$\overline{y2}$ = 11.725	$\overline{y3}$ = 13.525

4. The test statistic is defined as Fstat = MS_B / MS_W = 8.85 / 0.37 = 23.92

5. The critical values are in the **F table in Appendix VIII**. The table is indexed by the degrees of freedom associated with the numerator and denominator of the fraction used to calculate F. In this case the numerator **MS_B has 2 degrees of freedom** and the denominator **MS_W has 9 degrees of freedom**.

From the $F_{0.95}$ table in column 2 and row 9, Fcrit = 4.26.

The F statistic 23.92 exceeds the critical value 4.26, so it is in the reject region. So the null hypothesis is rejected.

Thus the conclusion is that at the 0.10 significance level, the data indicate that temperature does have an impact on moisture content.

REGRESSION ANALYSIS

Leadership thru' Business Excellence

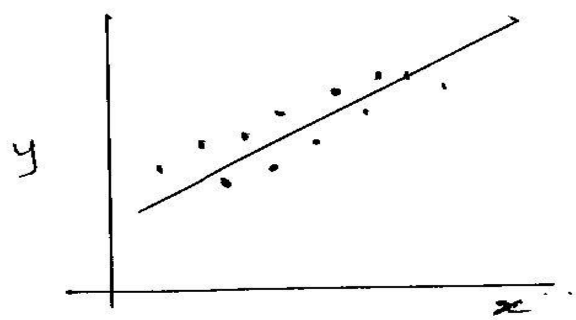
ASCB(E) Accrediting Certifying Bodies UK

Simple & Multiple Regression

- Suppose, we have data related to two variables
- Lets try to find an equation that shows relationship between these 2 variables.

1. First plot the data on a Scatter Diagram.

   If the trend indicates a straight line, then we try to find an equation that fits the data as the **best fitting line.**



Such a straight line is represented by the equation: $\mathbf{y = b_0 + b_1 x}$

where, $\mathbf{b_1} = \dfrac{S_{xy}}{S_{xx}}$

$$b_0 = \bar{y} - b_1 \bar{x}$$

$$S_{xx} = \Sigma x^2 - \frac{(\Sigma x)^2}{n}$$

$$S_{xy} = \Sigma xy - \frac{\Sigma x . \Sigma y}{n}$$

$$S_{yy} = \Sigma y^2 - \frac{(\Sigma y)^2}{n}$$

For example,

x	y	xy	x^2	y^2
10	2	20	100	4
15	3	45	225	9
20	5	100	400	25
15	4	60	225	16
60	14	225	950	54

$$S_{xx} = 950 - \frac{(60)^2}{4} = 50$$

$$S_{xy} = 225 - \frac{60 \times 14}{4} = 15$$

$$\therefore\ b_1 = \frac{15}{50} = 0.3$$

$$b_0 = \frac{14}{4} - \frac{0.3 \times 60}{4} = -1$$

$$\therefore\ y = -1 + 0.3X$$

* If we have value of x (**Predictor Variable**)

we can calculate y (**Response Variable**)

* We can also use the linear equation for extrapolation for values of

$x < 10$ or $x > 20$

Note: If Scatter plot does not show an approximate straight line, we cannot use linear regression.

* Similarly, we can have **multiple linear regression,** where we predict

value of ' y ' based on more than one predictor variables.

Typical regression equation would be

$$y = b_0 + b_1 x_1 + b_2 x_2 + \text{-- -- -- -- --} + b_k x_k$$

DESIGN FOR SIX SIGMA

* PUGH MATRIX
* QFD
* VOICE OF CUSTOMER – ETHNOGRAPHY, KANO MODEL
* CT MATRIX, QUALITY INDICATORS
* FMEA (re-visited)
* DMADV

DESIGN FOR SIX SIGMA (DFSS)

While most design processes barely deliver 2 or 3 sigma, DFSS can help you design or redesign a product or service in ways that will deliver about 4.5 sigma (1,000 DPMO) right from the start.

And do It in half the time. Why ? Because it forces you to think through all the options and potential tar pits before you commit people time, and money to a new product or service. As much as 70% of the total costs for a product can be traced back to the design process.

DFSS begins with the customer's needs, wants, and wishes (first External customers, then Internal customers) and translates them into CTQs.

There are several acronyms for the DFSS process - DMADV, IDOV, FISH but they all boil down to the same tools:

DMADV- **D**efine and **M**easure requirements. **A**nalyze options, **D**esign the process, and **V**alidate its performance.

IDOV- **I**dentify customer requirements, **D**esign best solution, **O**ptimize design and performance, **V**alidate its performance.

FISH – **F**ind out what your customers want, **I**dentify the alternative ways to give them what they want, **S**elect the best overall solution and **H**armonize the resulting product, service, and process with ever changing requirements.

.

There are five key tools in the DFSS process:

- **Pugh Concept Selection Matrix.**
- **Quality Function Deployment (QFD).**
- **CT Matrix**
- **Failure Modes and Effects Analysis (FMEA).**
- **Design of Experiments (DOE).**

With these five tools we can virtually design / redesign any process to be better, faster, and cheaper.

Pugh Concept Selection Matrix

Design for Six Sigma

Why? To evaluate various design alternatives against an existing baseline.

When?
When evaluating design alternatives.

	A	B	C	D	E	F	G	H	I
			Design Concepts						
1	Pugh Concept Selection Matrix Comparison Criteria	Current Process (Baseline)	Plug and Play	Bolt and Screw		Concept 4	Concept 5	Concept 6	Concept 7
2	Faster Assembly		+	-					
3	Harder to accidentally disconnect		-	S					
4									
5	Criteria								
6	Criteria								
7									
8									
9									
10	Total +'s		1	0	0	0	0	0	0
11	Total -'s		1	1	0	0	0	0	0
12									
13	Compare current with	+ Better Alternative							
14	selected alternatives	- Worse Alternative							
15		S Same Alternative							
16									
17		Focus on alternative with the most +'s and fewest -'s							

QUALITY FUNCTION DEPLOYMENT(QFD)

QUALITY FUNCTION DEPLOYMENT (QFD) DIAGRAM:

QFD is a means of developing visual relationships between customer requirements (Voice of the Customer) and Technical Attributes / Requirements which the product should deliver in order to satisfy the customer.

It also enables benchmarking with competition.

It is a visual tool used to present the customer requirements in a manner that the technical persons in the organization can develop a better understanding of the customer requirements.

The concept was developed in Japan in 1972. The QFD diagram is also known as "House of quality".

QFD Example: Styrofoam coffee cup with Plastic lid (cover):

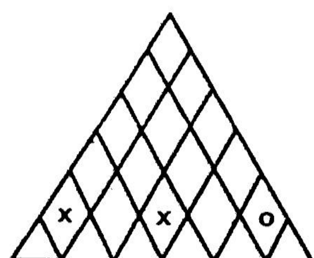
Customer Requirements:	Corresponding Technical Attributes (or Requirements):
Outer surface of cup must stay cool. (must not burn hand).	Temperature felt by hand.
Coffee must stay hot for at least 10 minutes.	Fluid temperature loss over time.
Cup must not spill liquid.	Clamping force at cover (plastic lid).
Cup will be rigid so as to resist squeeze. (when held in hand).	Fluid loss on vertical impact.
Cup will not leak.	Puncture resistance.
Material must be environmentally safe / friendly when disposed.	Degradable properties of cup / lid material.

Diagram 1: Customer Requirements Translated to Technical (Measureable) Parameters

Strong Relationship: xx
Moderate Relationship: x
Weak Relationship: o

		Temperature Felt By Hand	Fluid Temp. Loss Over Time	Clamping Force At Cover	Fluid Loss on Vertical Impact	Puncture Resistance	Degradable Prop. of Material
1	Outer Surface Must Stay Cool	xx	x				
2	Coffee Must Stay Warm (10 min)	x	xx				
3	Coffee Must Not Spill			xx	xx		
4	Cup To Be Rigid (No Squeeze)					x	
5	Cup Must Not Leak					xx	
6	Material Environmentally Safe						xx

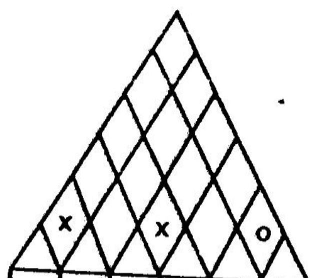
Diagram 2: Co-relationships between the Technical Requirements



Strong Relationship: xx
Moderate Relationship: x
Weak Relationship: o

		Temperature Felt By Hand	Fluid Temp. Loss Over Time	Clamping Force At Cover	Fluid Loss on Vertical Impact	Puncture Resistance	Degradable Prop. of Material
1	Outer Surface Must Stay Cool	xx	x				
2	Coffee Must Stay Warm (10 min)	x	xx				
3	Coffee Must Not Spill			xx	xx		
4	Cup To Be Rigid (No Squeeze)					x	
5	Cup Must Not Leak					xx	
6	Material Environmentally Safe						xx

Diagram 3: How Our Product compares to Main Competitor in terms of meting Customer Requirements

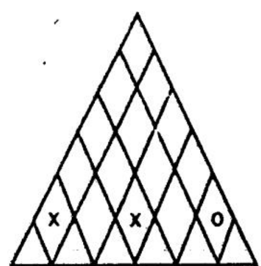


Strong Relationship: xx
Moderate Relationship: x
Weak Relationship: o

■ Competition
● Our Product
1 = Poor
5 = Excellent

		Temperature Felt By Hand	Fluid Temp. Loss Over Time	Clamping Force At Cover	Fluid Loss on Vertical Impact	Puncture Resistance	Degradable Prop. of Material	Customer Competitive Evaluations 1	2	3	4	5
1	Outer Surface Must Stay Cool	xx	x						■		●	
2	Coffee Must Stay Warm (10 min)	x	xx						■		●	
3	Coffee Must Not Spill			xx	xx					■ ●		
4	Cup To Be Rigid (No Squeeze)					x			●	■		
5	Cup Must Not Leak					xx					■ ●	
6	Material Environmentally Safe						xx			■	●	

Diagram 4: Actions to Improve our position with respect to main Competitor as indicated in Diagram 3



Strong Relationship: xx
Moderate Relationship: x
Weak Relationship: o

■ Competition
● Our Product
1 = Poor
5 = Excellent

		Temperature Felt By Hand	Fluid Temp. Loss Over Time	Clamping Force At Cover	Fluid Loss on Vertical Impact	Puncture Resistance	Degradable Prop. of Material	Customer Competitive Evaluations 1	2	3	4	5	Actions to Improve
1	Outer Surface Must Stay Cool	xx	x						■		●		Increase Glass Fibre in Styr.
2	Coffee Must Stay Warm (10 min)	x	xx						■		●		Increase Glass Fibre in Styr.
3	Coffee Must Not Spill			xx	xx					■ ●			
4	Cup To Be Rigid (No Squeeze)					x			●	■			
5	Cup Must Not Leak					xx					■ ●		
6	Material Environmentally Safe						xx			■	●		

Diagram 5:

A) **How Our Product compares to Main Competitor in terms of Technical Requirements (Measurable values like temperature - degrees C, force - kg, etc)**

B) **Operational Targets which our Product should meet to Satisfy Customer**

Example: The outside temperature of the cup should not exceed 110° F so that customer feels no discomfort

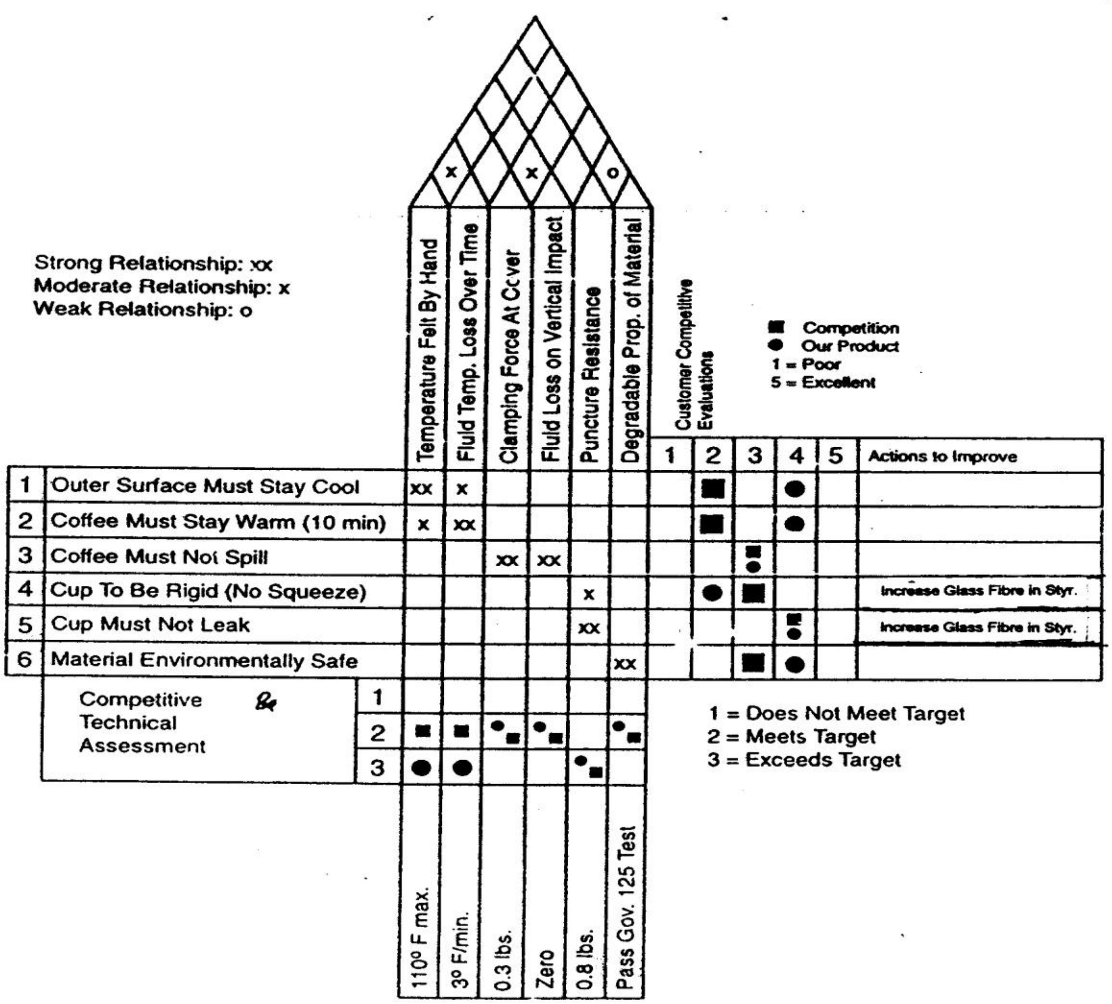
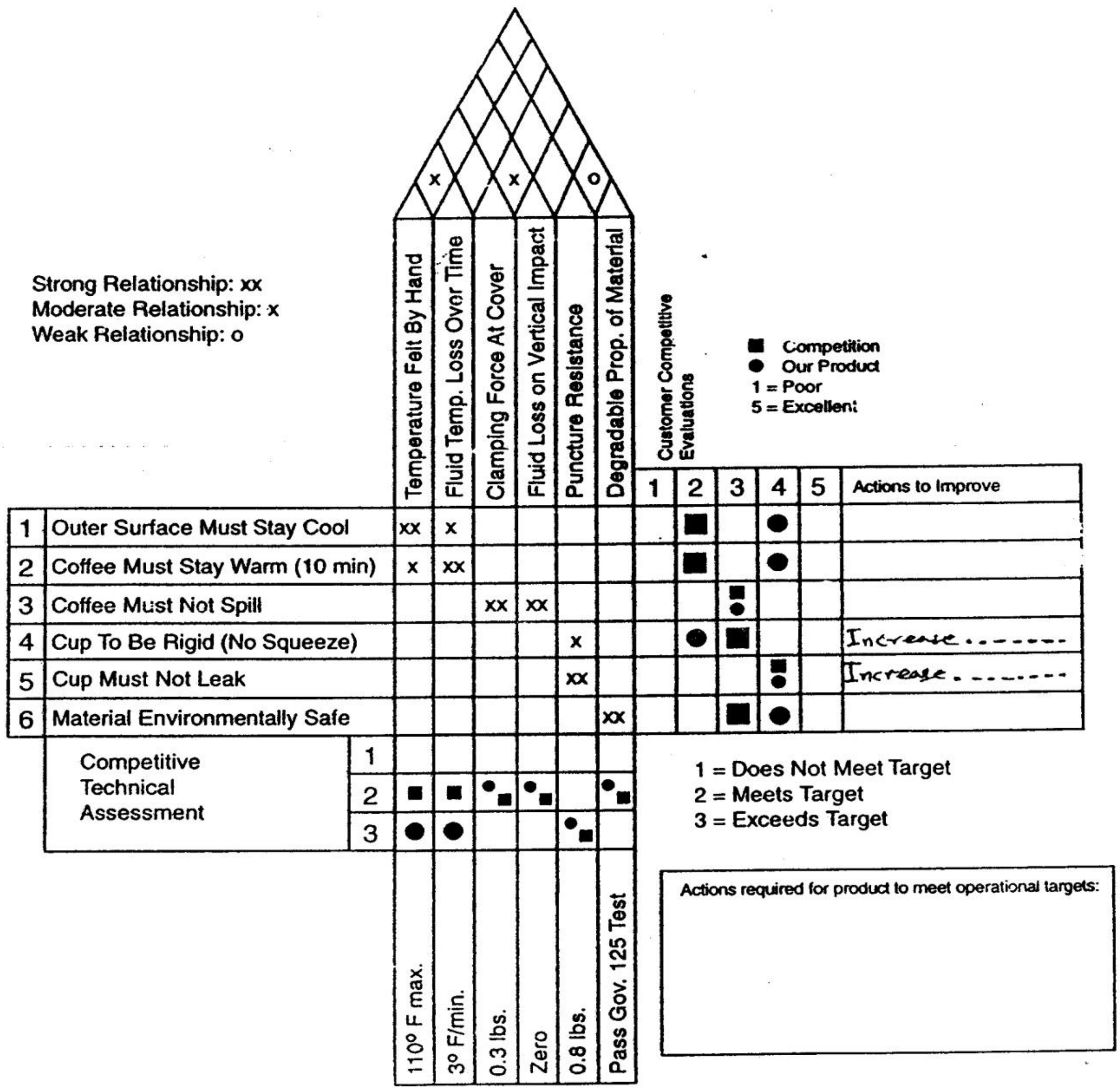


Diagram 6: Actions required (if any) so that product meets Operational Targets



VOICE OF CUSTOMER

* ETHNOGRAPHY
* KANO MODEL

ETHNOGRAPHY:

Understanding Voice of Customer :

Most companies today say they are using voice of the customer (VOC) data to make decisions. **But what exactly does that mean**?

In a 2002 survey by the Confederation of British Industry, with responses from more than 400 companies, the VOC methods mentioned included:

- **Surveys, 65 percent.**
- **Ideas meetings, 53 percent.**
- **Service / product testing, 50 percent.**
- **Formal observation, 18 percent.**

If a company's goal is to stay ahead of its competition, there are two fatal flaws with this state of affairs:

1. **These traditional forms of VOC collection are unreliable** even when the purpose is simply to improve what is already offered to customers. Odds of them helping the company push its market boundaries through innovation in products or services are virtually nil.

2. Most companies are not even making good use of these traditional methods. Pushed for details, **most managers will describe doing a survey once or twice a year, or say they get customer input only when testing a completely developed prototype.** That is far too late in the design process to have a significant impact.

Beyond the Traditional Forms of VOC:

There are some hard truths that businesses today are only just starting to grapple with. Most competitions in a particular field have access to the same customers and the same market information. **The organization that best understands those customers will end up with the biggest business advantage.**

Developing this level of understanding, demands skills well beyond traditional VOC techniques. **Customers usually cannot explain their needs or wishes that would lead to innovative or transformational products and services because.**

- **They do not know a supplier's capabilities as well as that supplier does – so it does not occur to them that a supplier may be able to help them solve a problem.**

- **Customer's creativity is more likely to be focused on their jobs than on the products or services they use.**

- **People are better at reaching to specific ideas than coming up with insights on their own.**

- **When customers are asked if they like a new offering, they may lie. They may not want to hurt anyone's feelings: or they may just want to avoid an argument.**

  Simply asking customers what they like or do not like about current products or services will not work. Microsoft made such a mistake by asking customers to attend a focus group. Use their software for a few hours, and answer questions interactively. It went something like this.

Question: Did you like the product?
Answer: Yup
Question: Any features you do not like or want to add ?
Answer: Nope

Based on these answers, it might appear that Microsoft had a winner right out of the gate. But when Microsoft developers began recording key-strokes and video-taping customers' experience, they discovered a wide range of negative customer reactions.

Ethnography: The New Science for understanding Customers:

If simply asking customers what they like will not work, what will? The answer is **incorporating close detailed observations of customers' behavior into the design work.**

The epitome of this strength is the emerging field of customer ethnography, where a company finds ways to **"Live with" selected customers to get an in-depth understanding of their needs and how they use a product or service in real life.**

Ethnography is a discipline built on the principles of social anthropology, studying people in their native habitat.(Of course, in a business contest, that habitat is more likely to be an office, school or home than the jungles of new Guinness)

At its simplest level, ethnography includes any direct observation of customers with an eye towards identifying things that could make their lives easier. For example, Scott Cook noticed how much time it took his wife to pay the monthly bills and how repetitive it was. This was the birth of his idea for **"Quicken",** the personal finance software which grew into a billion dollar company.

The practice of observing customer behavior has continued, now alive in **Intuit's** "Follow Me Home" research program which is designed to gather what is being called ethnographic customer data. Because of that, continued emphasis on understanding customers lives, “Quicken” and other “Intuit” products are consistently rated at the top of ‘easy to use software’.

The purpose of ethnography is to generate the kind of deep and intuitive understanding of customer needs and frustrations that cannot help but inspire creative insights. **A company will select about 10 customers (or potential customers) to be observed. (While other VOC methods are concerned with information quantity, ethnography focuses on quality).** A team of trained observers is sent to watch the customers. Their goals are to:

- Develop a **holistic view** of customer needs—look at all the behaviors associated with a particular need, not just a single task including all the activities that surround a product or service a supplier offers.
- Expose and record “**tribal Knowledge**” – the things that people do automatically, that they do not consciously think about.
- Identify **customer frustrations and areas of less than optimal** efficiency whether or not it is related to the product or service a supplier offers.

A Case Study in Ethnography:

Other than Intuit’s approach, no financial services business have made available reports on their use of ethnography, though Bank of America has set up an experimental branch where it can test any number of customer services. But the experience of a **retail chain** which wanted to improve customer experiences at its stores provides an example that could easily be adapted to banks with branch locations. This case study shows how ethnography complements more traditional forms of VOC.

The retail company team’s goal was to understand how it could redesign its stores to give shoppers a more pleasant experience (one that would co-relate into sales, of course). To get started the team :

- Looked at the current state of store layout and design and asked how that matched up what the customer “ wanted ”- as much as they knew at that point, at least.
- Reviewed existing quantitative data. Like most good companies, this retail chain had an abundance of market and consumer segmentation studies, marked share studies and business results on hand.

The team used this historical data as a starting point. (Many companies will stop here and not that this data is true and basing all their decisions on it. In fact such an assumption is seldom true.) Based on what was learned, the team began working on two different fronts:

1. **What Other Companies Were Doing (Benchmarking):**

The team made many trips to competitors' stores, did subjective evaluations of whether those designs seemed to be working, and looked for design features they could incorporate into their re-design effort.

Team members travelled far and wide searching for the newest, hottest store -design examples and concepts. The teams also looked at designs for other types of stores.

2. **What Customers Wanted (VOC Collection):**

- **The team went to customers, on their turf, visiting them in their own homes to hear about their issues and concerns.**
- The team also conducted **'shop-alongs'** going to various retailers with consumers to observe their reactions, asking for clarification on why they did what they did and capturing detailed notes on the consumer behavior.
- The team turned some staff into **'mystery shoppers'** who went to stores to shop for certain things and interact with the sales associates to see how customers are treated and what is offered to them.

Based on the information collected, the team moved into the **next design phase – proto-typing.** Though often used only for new product development, proto-typing is critical for all development efforts. This team took its research and incorporated them into miniature store layouts and designs.

For example, to test a completely new design of the music section, **they constructed (in open warehouse space) a scaled version of the new fixtures and layout. Then they brought in customers to test out the shop-ability of the new design. The feedback was immediately implemented into improving the design and establishing a second prototype, which also was tested.** The same process was used for each department until the store design was complete.

Conclusion: Getting New Insights

A growing body of case studies shows ethnography leads to insights that companies simply cannot get any other way. A book about this new discipline, The Art of Innovation by Tom Kelley, profiles IDEO, a firm in Palo Alto, California (USA). The firm has used ethnography to design everything from medical equipment to an office furniture showroom.

One downside of ethnography is that it is **time-and labor-intensive.** Also a company needs to guard against designing a product or service based on just a few customers. The experiences of the few people a business chooses to observe in depth can be a great source of inspiration and provide the starting point for next-generation products and services. But **the more traditional forms of VOC like surveys using personal / telephonic**

interviews– are still needed to validate findings from an ethnographic study.

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*About the author: **Anthony E Curtis** is a Master Black Belt at George Group specializing in applying Lean Six Sigma within service companies. With more than eight years experience in retail operations, he has managed projects in store operations, customer service, distribution, finance and marketing.*

Course Work Question Set

Q.1. What do you understand by the concept of Ethnography?

Q.2. Explain with example, how can you use the concept of Ethnography to understand voice of internal customer in your work situation.

Kano Model

Description:

Developed in the 80's by Professor Noriaki Kano, the model is based on the concepts of customer quality and **provides a simple ranking scheme** which distinguishes between essential and differentiating attributes.

This model helps in visualizing product characteristics and stimulating debate within the design team. Kano also produced a methodology for mapping consumer responses onto the model.

Product characteristics can be classified as:

- **Threshold / Basic Attributes :**

  Attributes which must be present in order for the product to be successful, can be viewed as a 'price of entry'. However, the **customer will remain neutral** towards the product even with improved execution of these aspects.

- **One Dimensional Attributes (Performance / Linear) :**

  These characteristics are **directly correlated to customer satisfaction.**

  Increased functionality or quality of execution will result in increased customer satisfaction. Conversely, decreased functionality results in greater dissatisfaction. Product price is often related to these attributes.

- **Attractive attributes (Exciters / Delighters) :**

  Customers get great satisfaction from a feature - and are willing to pay a price premium. However, satisfaction will not decrease (below neutral) if the product lacks the feature. These features are often unexpected by customers and **they can be difficult to establish as needs upfront.** Sometimes called unknown or latent needs.

Product differentiation can either be gained by a high level of execution of the linear attributes or the inclusion of one or more 'delighter' features.

But, it should be remembered that customer expectations change over time, and a cup holder in a car may be today's delighter, but tomorrow it will become a linear attribute.

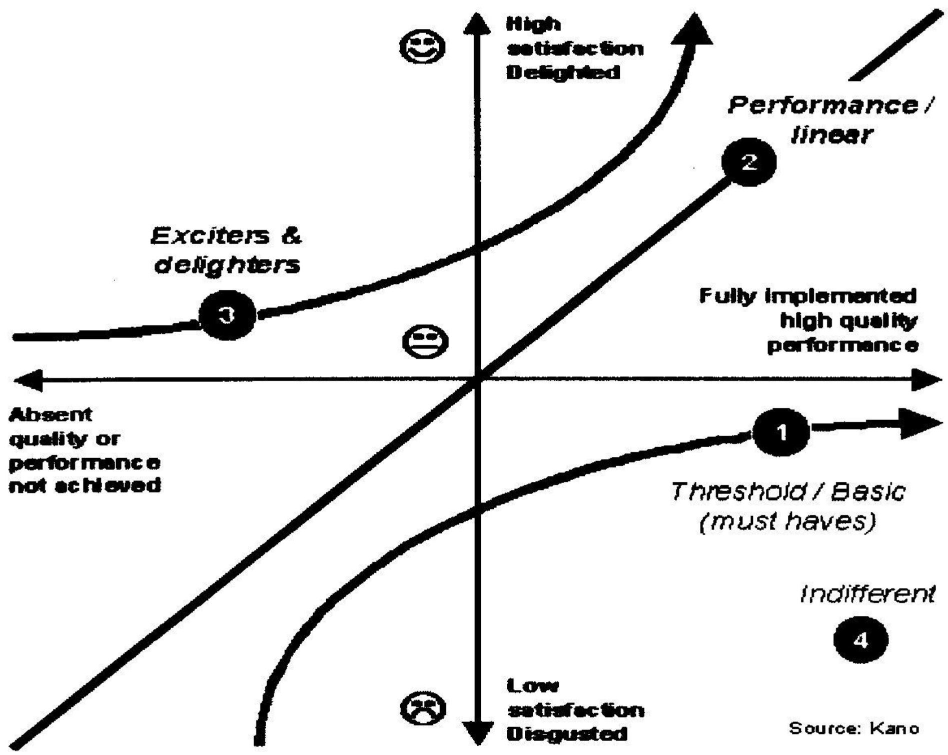


Figure -1: the Kano model

Method:

Kano developed a structured user-questioning methodology to help characterize different features and remove ambiguity by ensuring that categorization is based on user research.

CT MATRIX

Critical – To – Matrix (CT Matrix):

a) We need to understand customer requirements that are Critical – to – Quality (CTQ) i.e. the characteristics which very important to customer.

b) We also need to understand Critical – to – Process parameters (CTP) i.e. The parameters in the process which are critical for customer satisfaction,

The CT Matrix is used to display relationship between the customer requirements and the process parameters. For example:

PROCESS STEPS

			Write Order	Give Order to Cook	Assemble Pizza	Bake	Package	Deliver to Customer	Collect Payment
VOICE OF CUSTOMER (CTQ RATINGS)	**Hot Food**								
	Right Pizza								
	Taste								
	Fast Delivery								
	Fair Price								
	Courtesy								
	Range of Toppings								

Strength of relation between VOC and Process – Steps are expressed on 1 – 5 scale.

- **Strong relation – 5**
- **Medium relation – 3**
- **Low relation - 1**

Cumulative Scores are calculated for each Process steps as under:

a) Write Order =

b) Give Order to Cook =

c) Assemble Pizza =

d) Bake =

e) Package =

f) Deliver to Customer =

g) Collect Payment =

*** Higher the cumulative score, higher the importance of that process step.**

This helps the technical people to have clear priorities, and focus on the right processes, i.e. the processes which have higher impact on customer satisfaction.

DESIGN FMEA
READY RECKONER

Failure Modes & Effects Analysis
FMEA

FMEA

FMEAs help analyze the design of a part or assembly to: 1) identify potential failures, 2) rank these failures, and 3) find ways to eliminate these problems *before* they occur. FMEAs proactively, rather than reactively, reduce the defects, time, and cost associated with potential errors by preventing crises.

FMEA

Process

Benefits

- Improves quality, reliability, and safety.
- Reduces development costs and time
- Improves customer satisfaction
- Helps select optimum design alternatives
- Identifies potential interactions
- Provides a basis for developing diagnostic and management procedures.

Step	Activity
1.	Enter part name and/or block diagram the components
2.	List each potential failure mode
3.	Describe effects of each type of failure
4.	Rank severity of failure (see below)
5.	Classify any special characteristics
6.	List every potential cause or failure mechanism for each failure mode.
7.	Rank the likelihood of occurrence of each failure/cause
8.	List prevention/detection controls
9.	Rank detection (see below)
10.	Identify actions to reduce severity, occurrence, and detection.

Severity of Effect:	Customer Experience:	Part
1. None		
2. Very Minor	Not annoyed	Fit/finish/squeak/rattle
3. Minor	Slightly annoyed	
4. Very Low	Minor annoyance	
5. Low	Some dissatisfaction	Comfort items impaired
6. Moderate	Discomfort	Comfort items inoperable
7. High	Dissatisfied,	operable but impaired
8. Very High	Very dissatisfied,	inoperable
9. Hazardous with warning	Potentially hazardous effect (gradual failure)	
10. Hazardous w/o warning	Sudden, hazardous failure	

Occurrence Rating	Sigma Level
1. Remote <.01/1000	
2. Low - 0.1/1000	5 Sigma
3. Low - 0.5/1000	
4. Moderate - 1/1000	
5. Moderate - 2/1000	
6. Moderate - 5/1000	4 Sigma
7. High - 10/1000	
8. High - 20/1000	
9. Very High 50/1000	3 Sigma
10. Very High >100/1000	2 Sigma

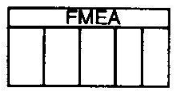
Likelihood of Detection:
1. Almost Certain
2. Very High
3. High
4. Moderate High
5. Moderate
6. Low
7. Very Low
8. Remote
9. Very Remote
10. Absolute Uncertainty

PROCESS FMEA
READY RECKONER

Failure Modes & Effects Analysis

Process FMEA

PFMEA



PFMEAs help analyze a process to: 1) identify potential failures, 2) rank these failures, and 3) find ways to eliminate these problems *before* they occur. FMEAs proactively, rather than reactively, reduce the defects, time, and cost associated with potential errors by preventing crises.

PFMEA

Process

Step	Activity
1.	Flowchart the process
2.	Describe process and function
3.	List each potential failure mode
4.	Describes effects of each type of failure
5.	Rank severity of failure
6.	Classify any special characteristics
7.	List every potential cause or failure mechanism for each failure mode.
8.	Estimate the likelihood of occurrence of each failure/cause
9.	List prevention/detection controls
10.	Rank detection
11.	Identify actions to reduce severity, occurrence, and detection.

Benefits

- Assists in designing controls to reduce or prevent the production of unacceptable products
- Establishes priorities for improvement efforts
- Documents the rationale for process choices

Severity of Effect:	Occurrence Rating	Detection:
1. None	1. Remote <.01/1000	1. Almost Certain
2. Very Minor	2. Low - 0.1/1000	2. Very High
3. Minor	3. Low - 0.5/1000	3. High
4. Very Low	4. Moderate - 1/1000	4. Moderate High
5. Low	5. Moderate - 2/1000	5. Moderate
6. Moderate	6. Moderate - 5/1000	6. Low
7. High	7. High - 10/1000	7. Very Low
8. Very High	8. High - 20/1000	8. Remote
9. Hazardous with warning	9. Very High 50/1000	9. Very Remote
10. Hazardous w/o warning	10. Very High >100/1000	10. Absolute Uncertainty

DMADV - OVERVIEW

DMADV - OVERVIEW

DMADV, which is similar to DMAIC is used when we are designing / redesigning a product / process.

D – DEFINE

M – MEASURE

A – ANALYSE

D – DESIGN

V- VALIDATE THE DESIGN

D	• **Define the goals (CTQs) of the design activity.** *** What is being designed?** *** Why?** • **Use QFD to ensure that the technical goals are consistent with the CTQ'S** • **Identify the Critical to Process parameters (CTPs) using CT matrix.**
M	• **Measure - the Critical to Process (CTP) metrics.** • **Establish the relationship of the CTQs with the CTPs.**

A	• **Analyze the options in respect of setting the CTPs for achieving the desired CTQs.** • **Determine the performance of similar best-in-class designs, through <u>benchmarking</u> to find best settings for the CTPs** • **Use Pugh Matrix to fine-tune the choice of design alternatives** • **Carry out FMEA for risk assessment and risk reduction in respect of the chosen design alternatives.**
D	• **Design the new product, service or process.** • **Conduct <u>Pilot runs</u> to VERIFY the effectiveness of the design - concept in meeting the goals.**
V	• **VALIDATE the design's effectiveness in the real-world through prototype trials and production-trials.**

DESIGN OF EXPERIMENTS

DESIGN OF EXPERIMENTS:

I. What is an experiment?

An experiment is a test or series of tests in which purposeful changes are made to the input variables of a process, so that we may observe (and identify the reasons for changes that may be observed) in the output response.

Experiments can be conducted in many areas like engineering, physics, chemistry, etc. In engineering, experiments help us for :

a) New product design,

b) Development of manufacturing or other processes.

c) Improvement of manufacturing or other processes.

A process is generally a combination of the 5 Ms that transforms some input (material) into an output. The output of the process depends on a number factors, which can be of Controllable Type or Uncontrollable Type (Fig. 1).

The person conducting an experiment is called the experimenter. His objective is to determine what influence these factors have on the output of the process. How he plans and conducts the experiment is called the strategy of experimentation.

Controllable Factors x1, x2, x3....

↓ ↓ ↓

Inputs → | PROCESS (Combination of resources like materials, men, money, machines, methods) | →Output (y)

↑ ↑ ↑

Uncontrollable factors z1, z2, z3....

Fig.1: General model of a process (or system)

2.Typical objectives of an experiment:

Some typical objectives of an experimenter are:

a) To determine the variables (x1,x2, x3--) which are <u>most influential</u> on the response 'Y',

b) To determine where to set the influential x's, so that the y is almost always near the desired nominal value,

c) To determine where to set the influential x's so that variability in y is small,

d) To determine where to set the influential x's so that effects of the uncontrollable variables z1, z2, z3 ------- minimized.

3. Strategy of Experimentation:

a) **Factors (F)** are the process parameters like:

- Temperature
- Pressure
- Current
- Voltage

b) **Levels (L)** are the choices available for setting the process parameters e. g. temperature may be set at two different levels T1, (200° C) and T2 (300°C).

c) **No. of outcomes (Results)** = (Levels)factors i.e. (L) F

Hence, in a 2-level, 2-factor experiment the number of outcomes will be (2)2 = 4,

In a 2-level, 4-factor experiment the number of outcomes will be = (2)4 = 16.

Some typical strategies of experimentation are:

(i) **Best guess approach:**

The experimenter keeps on adjusting the combination of factors based on his hunch and process knowledge to arrive at the optimum combination.

Demerits of this approach are:

* It can take a long time, with no guarantee of success

* If the experimenter gets an acceptable result in the first for attempt, he may be tempted to stop experimenting. It means he may never reach the "best solution".

(ii) **One-factor at a time approach:**

The experimenter selects a starting point or baseline set of levels for each factor. Then he successively varies each factor over its range, while keeping the other factors constant at the baseline level.

After all the tests are completed, a series of graphs are constructed to show how the output response is affected by different levels of each factor (while other factors are kept constant).

<u>Demerit</u> of this approach is that:

* It fails to consider any possible interaction between the factors. The <u>interaction</u> effect can lead to an entirely different output response.

(iii) **Factorial experiments:**

This is an experimental strategy in which factors are varied together instead of one at a time. It enables the experimenter to investigate the <u>individual effects</u> of each factor and to determine the <u>interaction effects</u> of these factors.

Factorial experiments help in making the most efficient usage of experimental data.

Generally if there are 'k' factors, each at 2 levels then the number of runs required will be <u>2k.</u>

However it may not be necessary to run all possible combinations of factor – levels (full – factorial experiment). Based on process – knowledge, the experimenter can choose the most influential factors and run the experiments for all factor – level combinations for these influential factors only.

E.g. If we conduct only 8 runs instead of the original 16 runs for a **24** experiment strategy, then its called a **<u>one – half fraction</u>** factorial experiment.

Types of Factors Factorial Designs:

Controllable and Measurable:

These factors can be easily adjusted (time, pressure, current,

Constant :

These factors do not influence the experimental results e.g. ambient temperature or relative humidity, certain machine parameters -

Noise :

These are factors which we have little or no control over the experiment results (variation in raw materials received from different suppliers, temperature variation in the factory, machine vibration).

Measurable but not Controllable :

The variation in these factors can be measured but cannot be controlled e.g. fat content in milk, sulfur content in diesel fuel.

Coding the Input (Experiment) Factors:

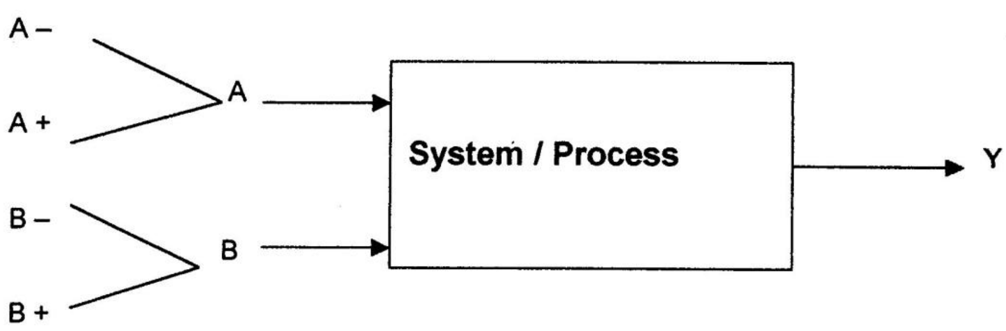
A - pressure measured in psi (lbs. per sq. inch)

B - temperature, measured in degrees Celsius

C - velocity, measured in cm. per sec.

Since the scales (dimensions) or the input factors A, B, and C are different, the coding process standardizes all factors to one scale and the effects of these factors may be compared quite easily. That is, the relative effects of the input factors on the output may be readily evaluated.

Designing an Experiment:



Possible combinations of inputs:

A - B -
A - B +
A + B -
A + B +

Number of combinations (runs) (Levels) factors (L) F = (2) 2 = 4

Run	A	B	Y (to be measured from experiment)
1	-1	-1	----
2	-1	1	----
3	1	-1	----
4	1	1	----

If there are 3 inputs at 2 level number of runs = (L) F = (2)3 = 8

Run	A	B	C	Y
1	-1	-1	-1	----
2	-1	-1	1	----
3	-1	1	-1	----
4	-1	1	1	----
5	1	-1	-1	----
6	1	-1	1	----
7	1	1	-1	----
8	1	1	1	----

8. Designing an Experiment – the Orthogonal Array:

Experiment 2 levels and 4 factors (A, B, C, D)

Number of runs (levels) factors = (2) 4 = 16

Let the levels be coded as -1 and 1, where -1 low, 1 high

Run	A	B	C	D
1	-1	-1	-1	-1
2	-1	-1	1	1
3	-1	1	-1	-1
4	-1	1	1	1
5	-1	-1	-1	-1
6	-1	-1	1	1
7	-1	1	-1	-1
8	-1	1	1	1
9	1	-1	-1	-1
10	1	-1	1	1
11	1	1	-1	-1
12	1	1	1	1
13	1	-1	-1	-1
14	1	-1	1	1
15	1	1	-1	-1
16	1	1	1	1

23. Design of Experiments Car Mileage – Example

1. Dependent Variable y = Car Mileage

2. Independent Variable = X's

   a) Tyre Pressure – 30, 35

   b) Octane – 87, 92

   c) Speed – 55, 65

3. No. of Tests = $2^3 = 8$

4. **Experiment:**

Tyre Pressure	Octane	Speed	Car Mileage
30	87	55	26
35	87	55	27
30	92	55	30
35	92	55	33
30	87	65	18
35	87	65	21
30	92	65	19
35	92	65	22

5. **Analysis:**

Tyre Pressure		Octane		Speed	
30	35	87	92	55	65
26,30,18,19 AV. 23.25	27,33,21,22 AV. 25.75	26,27,18,21 AV. 23	30,33,19,22 AV. 24	26,27,30,33 AV. 29	18,21,19,22 AV. 20

Design of Experiments

Robust Design for Six Sigma

Purpose Experiment efficiently to create robust designs

The purpose of DOE is to quickly and efficiently discover the optimum conditions that produce top quality. Trial-and-error is the slowest method of discovering these optimal conditions and usually misses the effects of various interactions. DOE significantly reduces the time and trials necessary to discover the best combination of factors to produce the desired level of quality and robustness.

Design Factors

	A	B	AB
1	-	-	+
2	+	-	-
3	-	+	-
4	+	+	+

Many factors affect the quality of a good or service. In manufacturing, time, temperature, pressure, etc. can all affect the quality and durability of a part or product. There may also be interactions among these various factors that affect product quality and robustness. For example, the amount of time various coats of a car's finish are baked at various temperatures will affect the durability of the paint over time.

DOE can also be used in service industries although it takes a little more thought to determine the factors, their high (+) and low (-) levels, and to quantify their interactions.

DOE Process

DOE Designs

Full Factorials
$2^2, 2^3, 2^4$

Focus	1. Determine objectives (biggest-smallest, most-least, closest to target), potential causes, and factors (usually 2, 3, or 4 factors). 2. Select experimental factors, identify potential interactions, and levels (+/-,high/low) 3. Choose appropriate design (4, 8, or 16 trials) and randomize sequence of trials
Improve	4. Run the experiment 5. Analyze the data to determine interactions and best factor levels 6. Verify results
Sustain	7. Implement the optimum factors

SIRPORC DIAGRAM

SIRPORC (SIPOC)

THE ACTUAL SEQUENCE: P –> O –> C –> Rc –> S –> I -> Rs

Supplier	Input (for process Sub-step)	Requirements (to be fulfilled by supplier)	Process (Sub-Steps)	Output (from process Sub-step)	Requirements (of customer)	Customer

HOW TO BUILD A SIRPORC:

START FROM INSIDE-OUT, BEGINNING AT THE CENTRE WITH THE PROCESS:

A) IDENTIFY THE PROCESS WE WISH TO MAP

LIST THE SUB-PROCESSES (PROCESS SUB-STEPS).

B) LIST THE RECIPIENTS / CUSTOMERS OF THE OUTPUTS.

C) IDENTIFY THE OUTPUTS

- **WHAT ARE THE PRODUCTS AND / OR SERVICES THAT WILL BE PRODUCED BY THE PROCESS?**

D) DEFINE THE CUSTOMER REQUIREMENTS (AND EXPECTATIONS) IN RESPECT OF THE OUTPUTS.

E) DEFINE THE INPUTS TO THE PROCESS:

- **WHAT ARE THE HUMAN, CAPITAL, INFORMATION, MATERIALS, AND OTHER RESOURCES REQUIRED BY THE PROCESS TO PRODUCE THE IDENTIFIED OUTPUTS?**

F) IDENTIFY THE SOURCES (SUPPLIERS) OF THE INPUTS.

G) DEFINE THE REQUIREMENTS (AND EXPECTATIONS) FROM THE SUPPLIERS OF INPUTS.

- **THE SIRPORC GIVES US A FULLY-CONTAINED, HIGH-LEVEL VIEW OF ANY PROCESS.**

- **IT HELPS US TO LOOK AT THE PROCESS FROM START TO FINISH.**

- **SIRPORC IS BUILT IN THE DEFINE STAGE.**

IT HELPS US TO:

- **Identify the CTQs and CTPs by looking at "Requirements of Customer" and "Requirements to be fulfilled by Supplier"**

SIPOC Diagram — *Fictitious Car Dealer Example*

Suppliers	Inputs	Process	Outputs	Customers	Requirements
Manufacturer	Cars	See Below	New Client Account	Car Buyer	Color Selection
Suppliers	Option Packages		Paperwork To State	Dealership Owners	Build To Order
Gas Station	Fuel For Cars		Paperwork To Dealer	Department of Motor Vehicles	Paperwork Filed Within 48 Hours Of Car Purchase
Sal's Car Wash	Car Washes		Paperwork To Manufacturer	Service Dept	In-State Checks Or Money Orders
Printer	Car Needs Worksheet		Payment		
			Service Contract		
			Service Notifications		

Meet With New Client → *Understand Client Needs In New Car* → *Present Options To Client And Test Drive Cars* → *Come To Agreement on Options, Price and Delivery Date* → *Sign Paperwork and Hand Over Keys/Title*

SELECTING THE RIGHT PROJECTS - PARETO PRIORITY INDEX

Selecting the Right Projects

What is a Six Sigma Project?

Six Sigma is about solving business problems by improving processes. Typical problems fall into two major categories:

1. Solution known:

One category of problems frequently encountered is that in which the solution is known at the outset.

Such problems include areas like:

- Implementing a new computer network to conform to corporate guidelines
- Installing a new piece of equipment in manufacturing
- Building a new plant are examples of known-solution projects.

Most capital projects also fall into this category.

In these situations it is known what has to be done. The project is completed by assigning a project manager to the project, providing the needed resources, and using good project management techniques.

Six Sigma techniques are generally not needed here, although project management can benefit from the process thinking, measurement, and monitoring techniques used by Six Sigma.

2. Solution Unknown:

Six Sigma is aimed at solving the problem in which the solution is not known.

Such problems include areas like:

- Decreasing errors in invoices

- Increasing the efficiency or safety of a process
- Decreasing the defect rate in the output of a process
- Decreasing the days outstanding in accounts receivables.

An organization's improvement plan typically includes projects of both types: solution known and solution unknown. Both types of projects are important and are needed to improve the performance of an organization.

*** Solution-unknown projects are led by Black Belts or Green Belts**

*** Solution-known projects are lead by project managers.**

To use Six Sigma, you need one or more measurements that quantify the magnitude of the problem and can be used to **set goals and monitor progress**.

These measurements are critical to quality (CTQ) measures.

Selecting Good Six Sigma Projects

The typical characteristics of a good Six Sigma project are—

- **Clearly connected to the business priorities**

  * The Project should be clearly linked to business priorities, as reflected by the strategic and annual operating plans.

- **Problem is of major importance to the organization**, e.g.

* Major improvement in process performance (say >50%)

* Major financial improvement (say > 0.5 Million US $ / year)

The project must address a critical problem that needs to be solved for the organization's success.

A project should **represent a breakthrough** in terms of major improvements in both process performance and significant bottom-line results.

The determination of project impact is normally done by the Finance function working in cooperation with the Black Belt and Champion. The financial impact is calculated for each Six Sigma project.

Everyone concerned must know what the project is worth in terms of the bottom line before work begins.

- **Reasonable scope, generally should be completed in 4-6 months**

* Support for project often decreases after 6 months

* A very large Project scope becomes a common problem.

It is important that projects be completed within a defined time frame in order to keep the organization and resources focused on the project. Organizations typically lose interest in projects that run longer than six months.

Projects requiring more than six months of effort can usually **be divided into sub-projects of shorter duration**, with the projects being conducted sequentially or in parallel.

- **Clear quantitative measures** of what will be considered as success

* Baseline, goals, and entitlement well-defined.

- **The project would be considered as valuable to the organization**

* People will support a project that they understand and perceive as important.

- The project has the **support and approval of senior management**

  * This is needed to get resources, remove barriers, and sustain over time.

  The importance of the project to the organization should be clear, and the project should have the full support and approval of management. The above are **generic attributes of a good project**.

- **The organization also has to develop their own specific project selection criteria** which will produce significant bottom-line results for them.

Some <u>sources for identifying projects</u> that would make a major impact are:

- Activities leading to rework and scrap
- Processes where productivity is low
- More unhappy (internal and external) customers
- Sources of waste and hidden losses
- Delays in meeting schedules / time requirements for customers
- Problems needing solutions to meet annual operating plan
- Major problems which can have financial impact for the organization
- Large budget items like receivables, payables, taxes, etc.
- Cost of Quality studies.

Projects that should be avoided:

Typical characteristics of projects that should be avoided, or at least refined further, would include examples like:

- **Unclear objectives** - The goals of the project must be clearly specified.
- **Poor metrics** - The process metrics such as accuracy, cycle-time, cost , should be clearly defined, and have baseline values identified.
- **No tie-up to financials** - The project must be tied to the bottom line.
- **Very broad scope** - An unrealistic scope (often referred to as a "boiling the ocean" project) is one of the most commonly encountered cause of project failure.
- **Solution already identified** - Projects with an "identified solution" should be handled by a project - manager instead of the six sigma team.
- **Too many objectives**
- **No connection to strategic or annual plans**.

How to select the projects?

1. **Establish a Project-Selection Steering Committee:**

   This committee would consist of process-owners (champions) and black belts.

2. **Generate Project Ideas:**

   Look for areas like those:

   a) That are causing frustration in the organization

   b) Burning issues and problems

   c) Opportunities not tapped.

The Steering Committee should compile a list of such project opportunities along with supporting-project-rationale data.

The process owners then discuss these opportunities with their team-members to evaluate which process improvements would benefit:

- The Customers
- The Business
- The Employees
- The Suppliers

3. **After these evaluations, the Steering Committee will meet for a formal Project Selection Workshop with the objective of:**

a) Reviewing all the identified projects

b) Reviewing the expected benefits of each project

c) Fixing priorities for each project in terms of benefits expected and value to the organization.

4. Cost – Benefit Analysis For Six Sigma Projects:

A commonly used metric is the **Pareto Priority Index** (PPI)

$$PPI = \frac{\text{Savings x Probability of success}}{\text{Cost x Completion time}}$$

a. Probability of Success will be determined on the basis of factors like:

i) Extent of involvement by senior management

ii) Extent of involvement by process owner (champion)

iii) Availability of data for the essential metrics

iv) Extent of technical knowledge required and available in the process.

b) Cost estimates will include:

i) Cost of labour and materials required for the project

ii) Cost of deployment of the black belt and green belts

iii) Cost related to collection of data.

Based on these factors a budget is prepared. The black – belt needs to review and update the budget related performance as the project proceeds.

c) The **Savings** are calculated with help of the Accounts / Finance Department so that fair and accurate estimates of the savings are worked out.

This will ensure consistency across projects and prevent bias which may occur due to a particular black belt's or champion's calculations.

EXAMPLE OF PPI TO EVALUATE POTENTIAL OF DIFFERENT PROJECT OPTIONS:

Project Name	Saving Potential (US $)	Probability of Success (P)	Estimated Cost (US $)	Completion Time (Months)	PPI
P.O. Cycle Time	2,200,000	0.9	60,000	4	10.2
Transit Damage	3,500,000	0.7	98,000	6	8.5
Change in Product Design	5,600,000	0.6	190,000	9	5.4
Project Turnaround Time	7,300,000	0.5	400,000	10	3.6

SSBB PROJECT:
TEMPLATE FOR PROJECT CHARTER

	AIQM LSS Project Charter	Doc. Control #	
		Version	1.0
		Date	

1.	LSS Project Reference Number and Name:
2.	Details of the Process to be Improved: Note: This could be a process whose outcome is resulting in dissatisfaction of an external customer or an internal customer.
3.	Process Owner & Champion: • Name: • Email:
4.	Who is / are the Customer(s)of the Process?
5.	LSS Project Leader (Black Belt or Green Belt): • Name: • Email:
6.	LSS Project Team Members:

	Name	Email ID	Role in Project

7.	Name of technical expert(if any):
8.	The Business Need: Note: How will the project benefit the Customers in terms of Quality, Cost, Delivery. Also how it will benefit the organization?

9. What do you see as the critical factors (CTQs, CTPs, and Sub-CTPs) of the process?

CTQs	CTPs	Sub-CTPs

10. How would you rank the problems in order of priority?
(Based on CFT's Brainstorming, Pareto Analysis, etc.)

Problems related to Critical Factors	Rank (% Weightage)

11.	The Problem Statement(Quantification is a MUST):
12.	The Goal Statement (To be stated as a **SMART Goal**):

13. Boundaries of the Project:

In – Scope	Out – Scope

14. Improvements Expected from the Project:

Hard Gains (Expected savings from the project in terms of INR or USD)	Soft Gains (Like Image of organization, Reputation, etc.)

15.	Resources required for the Project:
16.	Chosen Methodology for the Project: **D-M-A-I-C**

17. List of Constraints (if any) & our Planned Responses:

Expected Constraints	Planned Responses

18.	Rules for the Team: • Meeting Day(s) of the Week (For Reviews): • Time Slot fixed for the Meeting(s): • Review Methodology within the team: • Methodology for Making Decisions: • Innovative ideas expected from each team-member • Minutes of Meeting and Documentation
19.	Assumptions/Guidelines, if any
20.	Plan for Interim Containment Actions(if any): **(Team should brainstorm and try to capture some low-hanging fruits)**

21.	Time Frame / Project Plans (generally spread over 4 to 6 months)

Milestone (And Review dates with MBB Expert)	Dates (Generally spread over 4 to 6 months depending on the project scope)
Define Phase Kick Off (Project Start)	
Define Phase Closing – Measure Phase Kick Off	
Measure Phase Closing – Analyze Phase Kick Off	
Analyze Phase Closing – Improve Phase Kick Off	
Improve Phase Closing – Control Phase Kick Off	
Control Phase Closing (Project Completion)	
Project Presentation to Management	

22.	Overview Process Map (SIRPORC) to be attached:
23.	Accountability Plan - ARIS **A**: [Person(s) who are ACCOUNTABLE for the Project] **R**: [Person(s) who are required to REVIEW the DMAIC Phases] **I**: [Persons whose INPUTS are required for the Project] **S**: [Person who is required to SIGN-OFF on completion of the task]

Project Start Date:	Target Completion Date:
Champion's Approval Signature:	Date:

Accountability Matrix – EXAMPLE:

(ARIS CHART)

Sr.	Task	Estimated Duration (days)	Champ	BB	Co-BB	GB	GB
1.	Project Roadmap	03	A				
1.1	Develop Roadmap	01	A	R	I	I	I
1.2	Roadmap Sign-off	02	S				
2.	Project Charter	07	S	R	I	I	I
2.1	Problem Statement	02	A	R	I	I	I
2.2	Mission Statement	01	A	R	I	I	I
2.3							
2.4							
2.5							
2.6	Rules for the team	03	-	S	R	I	I
3.2							

- **A:** Person who is ACCOUNTABLE for the task
- **R:** Person who is required to REVIEW the task
- **I:** Person whose INPUT is required for the task
- **S:** Person who is required to SIGN-OFF on completion of the task

THE DMAIC PROCESS – CHOICE OF TOOLS

DEFINE:

- Voice of Customer
- Quality Function Deployment
- Kano’s Model
- Benchmarking
- Determining the CTQs
- Project Charter
- SIRPORC
- Define Responsibility, Authority.

MEASURE:

- Identify the CTPs
- Data Collection Plan in respect of the CTPs
- Sampling Plan
- Questionnaire
- Measurement System Analysis
- Process Observations & Data Collection in respect of CTPs
- Process Capability Calculations.

ANALYZE:

- Process Mapping – Value Analysis
- Brainstorming
- Cause & Effect Diagram
- 5 Whys
- Histogram
- Box & Whisker Plot
- Historical Data Analysis
- Pareto Chart
- Regression Analysis
- Scatter Diagram
- z-test
- t-test
- ANOVA
- Develop Alternative Solutions.

IMPROVE:

- FMEA for chosen solution
- Mistake Proofing
- Pilot Trials - Verification
- Fine-Tune and Validate
- 5S Workplace Organization
- Visual Management
- Standard Work
- Kanban
- Total Productive Maintenance
- Revised Process Capability Calculations.

CONTROL:

- Authentication of Savings
- Documentation / Standard Operating Procedures / Work Instructions
- Training on SOPs / WIs
- Control Charts for CTPs &CTQs
- Audit Plan
- Handover to Champion.

USEFUL TEMPLATES FOR LSS ORGANIZATIONS

What is the Total Budget for This Project?

Projects consume resources. To accurately measure project success, it is necessary to keep track of how these resources are used. The total project budget sets an upper limit on the resources this project will be allowed to consume. Knowing this value, at least approximately, is vital for resource planning.

Project Budget Development

Budget Item	Estimated Expenditure Range	Charge Account #	Authorization
Team Meeting			
Team Member Time			
Contract Work			
Material			

How Will I Measure Project Success?

You should have one or more metrics for each project deliverable.

- Metrics should be selected to keep the project focused on its goals and objectives.
- Metrics should detect project slippage soon enough to allow corrective action to advert damage (i.e. the Process indicators)
- Metrics should be based on customer or sponsor requirement.

Deliverables Metrics

Deliverable	Validation Metrics	Frequency of Measurement

Refining the savings Opportunity Estimates.

Preliminary estimates of benefits were made previously during the initial planning. However, the data obtained by the team will allow the initial estimates to be made more precisely at this time.

Whenever possible, “characteristic” should be expressed in the languages of management: i.e. Dollars.

One needn’t strive for very accurate calculation; a rough figure is sufficient. It is recommended that the finance and accounting department develop savings estimates. However, in any case estimates must, at least, be accepted (in writing) by the accounting and finance department as reasonable. This number can be used to compute a return on investment (ROI) for the project.

As a general rule, savings estimates are made conservatively. That is, they do not consider the value of intangibles such as improved employee morale or customer satisfaction.

The approach is to consider the cost of the current process and to compare it with the cost of operating the improved process.

We can calculate the cost of a single error or problem, estimate the total number of errors or problems, and multiply to arrive at the “dollar size” of the opportunity. This is compared with the project’s cost and time to determine the ROI.

Example: Cost of Incomplete or Inaccurate Customer Data

The Six Sigma project involved improving the quality of data in a customer database at a call center.

Whenever a customer phones in, the representative looks for the customer's record in the database and verifies the information it contains. Based on a sample, it is estimated that about 11 % of the record in the database are incorrect and require attention by the representative. Considering only direct costs (labor), the estimated opportunity is calculated as follows:

Example of Cost-Benefit Opportunity Calculations:

Number of calls / year	1,300,000,
Average time to correct database	30 seconds (0.5 minutes)
Cost per minute	US $ 2.00
Size of opportunity	$ 2 x 0.5 x 1,300, 000 x 0.11 = $ 143,000/-
Estimated cost of project $ 32,000/-	No additional operating expense is expected.
Estimated improvement	Reduce errors by 90 %
Savings	$ 143,000/- less $ 14,300/- = $ 128,700/-
Time to complete	6 Months
Project ROI	**128,700 / 32,000 X 100 = 402 %**

Dollar Opportunity Estimate

Error or Problem	Cost Now	Cost After Improvement	Savings
TOTAL			

Project ROI	
Accounting Concurrence	

Historical Research Summary

Similar Project	Key Lessons	Comments #

Constraints – factors that limit the team's options – also need to be identified.

Constraint Analysis:

Constraint	Effect of Constraint	Planned Response to Constraint	Number

RUN CHARTS & CONTROL CHARTS

RUN CHARTS & CONTROL CHARTS

A) SHEWHART DEVELOPED CONTROL CHART AS A TOOL TO FIND WHEN THE PROCESS IS UNDER THE INFLUENCE OF:

- **COMMON (INHERENT) CAUSE OF VARIATION**

OR

- **SPECIAL (ASSIGNABLE) CAUSE OF VARIATION**

CONTROL CHARTS ARE USED FOR

DIAGNOSTICS

(TO ANALYSE THE NATURE OF VARIATION)

(ANALYSE PHASE)

MONITORING THE PROCESS

(CONTROL PHASE)

B) RUN CHARTS ARE ALSO CALLED AS PROCESS BEHAVIOUR CHARTS.

They are mostly used in DEFINE phase of DMAIC to make preliminary observation of trends in the process under study.

Leadership thru' Business Excellence

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Creating a characteristic or process behavior chart

To investigate the behavior of a characteristic or process, plot your observed measurements one at a time along an axis representing time or order, in the exact sequence the measurements occurred in real life.

To create a characteristic or process behavior chart:

1. **Create a horizontal scale representing time or order.**

   You usually do this by creating an axis for the order in which the measurements occurred, called their *run order*.

2. **Create a vertical axis representing the scale of measure for the characteristic.**

   This scale could be in millimeters for length, pounds for weight, minutes for time, number of defects found on an inspected part, or anything else that quantifies what it is about the characteristic you're interested in.

   Set the maximum and minimum values on this vertical scale just slightly larger and slightly lower than the maximum and minimum observed data values, respectively.

3. **Plot each observation as a dot using its order and measurement.**

4. **Connect the dots.**

   Draw a line between each sequential point to emphasize the change that occurs between observations.

Figure–E shows an example of a behavior chart for the completion time of an assembly process.

Interpreting characteristic or process behavior charts

Under normal conditions, a process or characteristic should behave normally. This statement is more profound than it sounds. The performance of every process or characteristic has natural variation. A behavior chart graphically shows how that variation plays out over time.

Like in Figure–E a process or characteristic has variation that bounces around a central, horizontal level on the behavior chart. Most of the observed variation will be clustered close to this central level. Also, every now and then, there will be excursions that are farther away from the center. The variation will be completely random over time, without patterns or trends. This type of behavior is the definition of *normal,* and is analogous to the entitlement level of variation covered in "Be all you can be: Entitlement" section.

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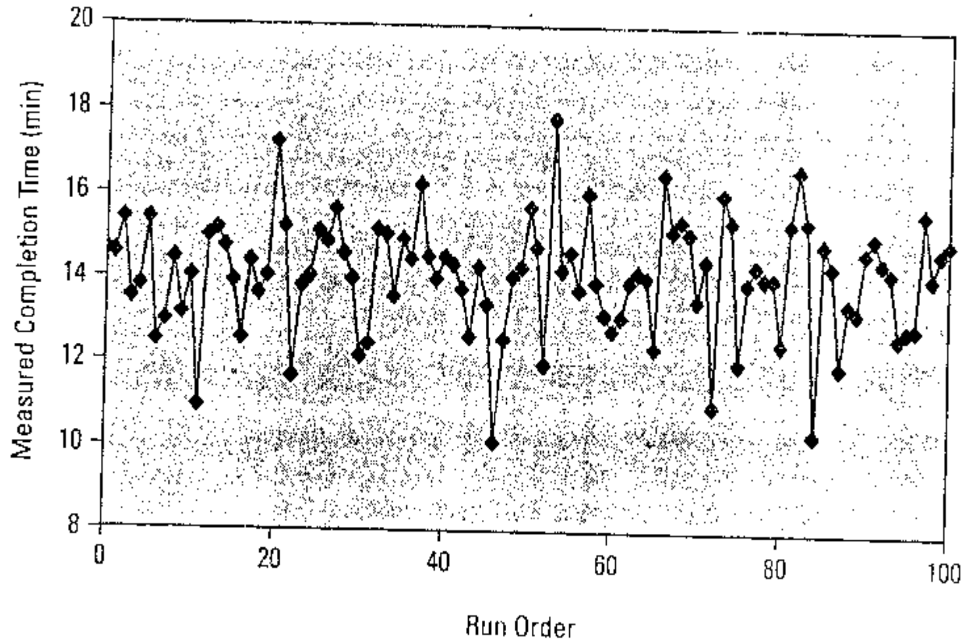


Figure—E Characteristic or process behavior chart example. Each observation of the characteristic is plotted in the order in which it was measured.

A behavior chart not only allows you to see the normal behavior of a process or characteristic, it also allows you to quickly detect *non-normal* behavior — variation above and beyond the expected normal level. The causes of non-normal behavior are the assignable or special causes spoken of earlier in this chapter that erode and degrade entitlement performance over the long term. Behavior charts form the foundation of detecting and finding the root cause of non-normal behavior.

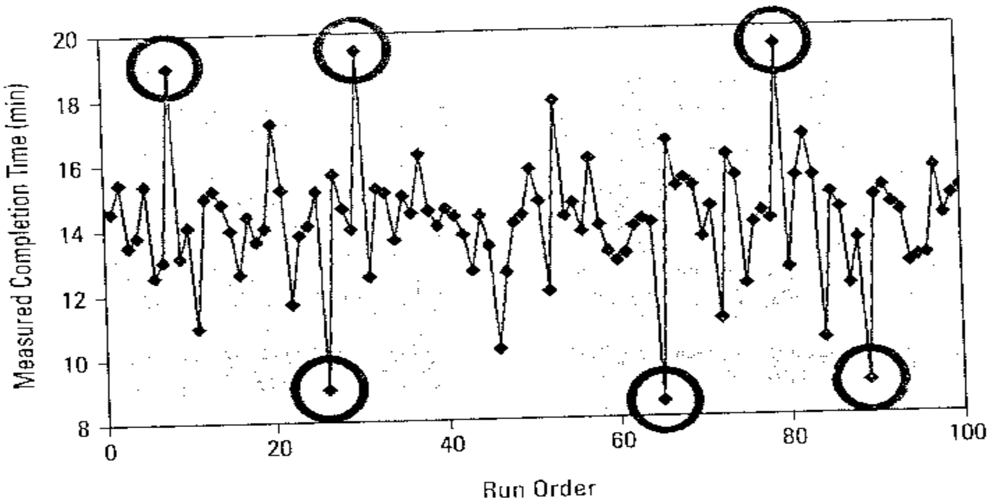
Things to look for in process and characteristic behavior charts:

- **Variation beyond expected limits:** Outliers are measurement observations that occur beyond the limits of the normal short-term variation you expect out of the process or characteristic.

  Outliers are non-normal because you don't expect to see them. It's like rolling five doubles in a row with a pair of dice. Five doubles in a row is possible, but when it happens, you suspect that something out of the ordinary is at play, like maybe a loaded pair of dice. ("Loaded" is just another way of saying the dice are acting non-normal.)

  Figure—F shows an example of a behavior chart showing evidence of variation beyond expected levels.

Figure — F
Behavior chart showing evidence of variation beyond the expected normal limits.



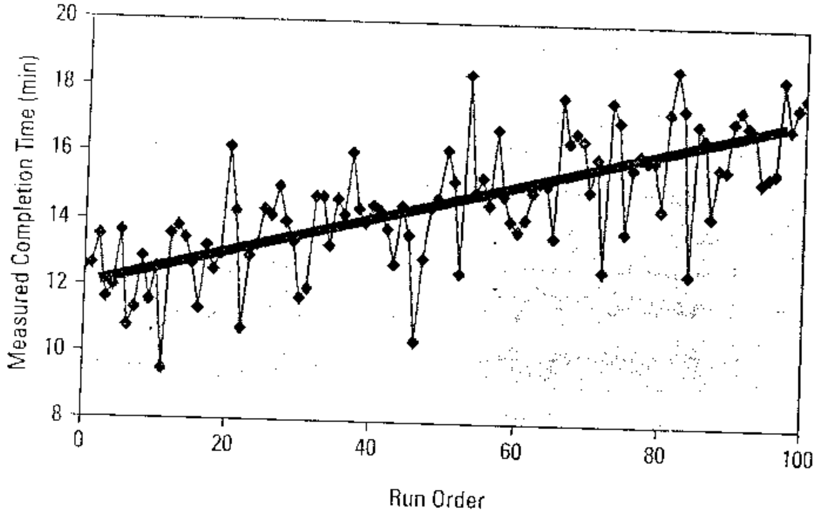
When you see excessive variation like this, use the time scale or run order of the behavior chart as a starting point to discover what conditions or factors are causing the non-normal variation. Go back to that point in time identified by the chart and ask yourself. what was different at this point in time to take the characteristic or process behavior out of its normal course? The answer allows you to identify and manage the factor or factors influencing the process or characteristic performance.

Typical causes of outliers include worker inattention, measurement errors, and other one-time changes to the process's or characteristic's environment. For example, there may be a data outlier for purchase order processing due to an emergency in the office where two workers had to leave at the same time — thereby leaving a purchase order in the queue for an excessive period of time.

✓ **Trends:** Trend is a steady, gradual increase or decrease in the central tendency of the process or characteristic as it plays out over time. If all the conditions in the system stay constant, the level of performance of the process or characteristic will also stay level. The presence of a trend in a graphical behavior plot is evidence that something out of the ordinary has happened to move the location of the process or characteristic behavior. Figure – G shows a sample of a trend in a process behavior chart.

Just like with any other evidence of non-normal behavior, when you see a trend in a behavior chart, you need to look closer at the system to uncover what is causing the changed performance.

Figure – G Behavior chart showing evidence of a trend in the location of the variation center over time.

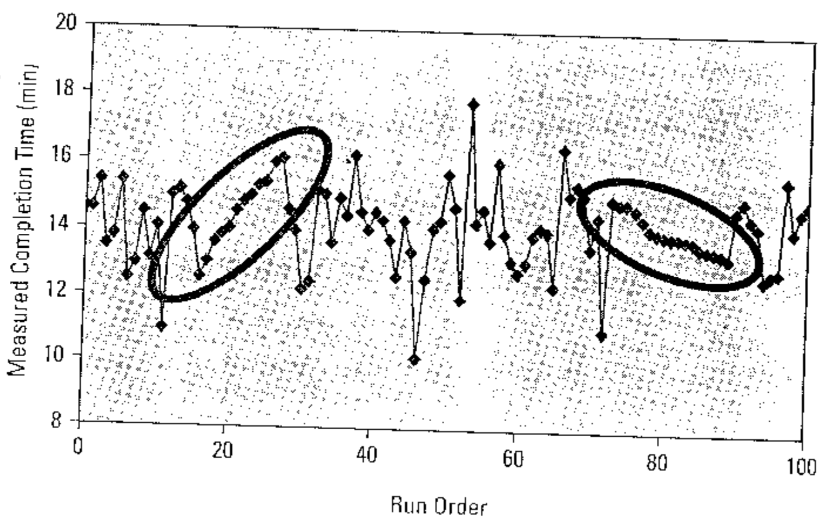


Trends in performance are almost always caused by system factors that gradually change over time, like temperature, tool wear, machine maintenance, rising costs, and so on.

- **Runs:** Run is a sequence of consecutive observations that are each increasingly larger or smaller than the previous observation. Figure – H shows an example of two runs, one increasing and one decreasing, within a behavior chart.

Runs can be caused by faulty equipment, calibration issues, and cumulative effects, among other things.

Figure – H Behavior chart with evidence of a run. A string of consecutive points that increase or decrease are not normal behavior.



✓ **Shifts:** Shifts are sudden jumps, up or down, in the process's or characteristic's center of variation. Something in the system changes permanently — a piece of equipment, a new operator, a change in material, a new procedure. Clearly, shifts are non-normal behavior.

Figure -J shows an example of a process or characteristic that has experienced a shift in the center level of its variation.

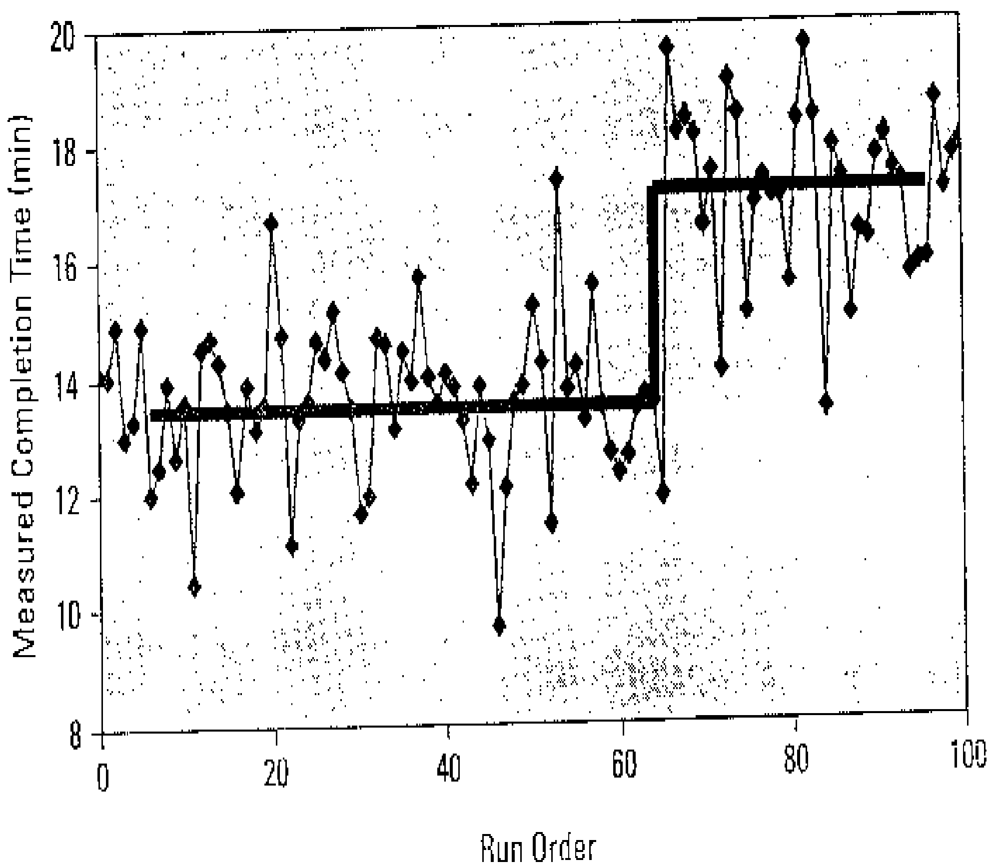


Figure-J Behavior chart with evidence of a non-normal shift affecting the level of the central tendency of the variation.

Selection and Application of Control Charts

Variables Charts

The $\bar{x}$ and R chart is the flagship of the control charts. It is called a variables chart because the data to be plotted result from measurement on a variable or continuous scale. This type of measurement occurs when, for each pair of values, there are an infinite number of possible values between them. On an inch scale, for instance, there are an infinite number of values between 1.250 and 1.251, values such as 1.2503, 1.2508, and so on. The $\bar{x}$ and s chart is another variables control chart. With this chart, the sample standard deviation, s, is used to indicate dispersion instead of the range. The standard deviation is a better measure of spread, especially if the sample size is large, so this chart is somewhat more precise than the $\bar{x}$ and R chart. The $\bar{x}$ and s chart should be used when calculation of the standard deviation is feasible. Users who are comfortable with the standard deviation function on a handheld calculator will be able to calculate s almost as easily as R. The $\bar{x}$ and s chart is also the preferred chart when the chart is constructed by using a software package.

Control Limits

Control limits are calculated based on data from the process. Formulas for control limits and examples of each are given in this section. The formulas are repeated in Appendix III. Several constants are needed in the formulas. These appear as subscripted letters such as A_2. The values of these constants are given in Appendix IV. When calculating control limits, it is prudent to collect as much data as practical. Many authorities specify at least 25 samples. The examples in the following sections use fewer samples for simplicity. It is very important that sample size be held constant.

$\bar{X}$ and R Control Charts

Control limits for $\bar{X}$ and R control charts are given by the following formulas:

Upper control limit for the averages chart: $UCL_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R}$

Lower control limit for the averages chart: $LCL_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R}$

Upper control limit for the range chart: $UCL_R = D_4\bar{R}$

Lower control limit for the range chart: $LCL_R = D_3\bar{R}$

Example: Data are collected in a face-and-plunge operation done on a lathe. The dimension being measured is the groove inside diameter (ID), which has a tolerance of 7.125 ± .010. Four parts are measured every hour. These values have been entered in Figure VIII.4.

Xbar and R Control Chart Machine_____ Process_____

Product/Part name & number ***mp plate w239*** Gage ***64e*** Specification limits 7.125±.010

Date/Operator ***3/17 Hoss***

Time		7am	8	9	10	11	noon	1pm	2	3	4		
	1	7.127	7.125	7.123	7.127	7.128	7.125	7.126	7.126	7.127	7.128		
	2	7.123	7.126	7.129	7.127	7.125	7.125	7.123	7.126	7.129	7.123		
	3	7.123	7.121	7.129	7.124	7.126	7.127	7.123	7.127	7.128	7.122		
	4	7.126	7.122	7.124	7.125	7.127	7.128	7.125	7.128	7.129	7.124		
	5												
Ave: $\overline{X}$		7.125	7.124	7.126	7.126	7.127	7.126	7.124	7.127	7.128	7.124		
Range, R		.004	.005	.006	.003	.003	.003	.003	.002	.002	.006		

Notes:

$\overline{X}$

R

Figure VIII.4 Measurement data entered in an $\overline{X}$ and R control chart.

The next step is to calculate the average ($\bar{x}$) and range (R) for each time. These values have been entered in Figure VIII.4. Next, calculate the average of the averages ($\bar{\bar{x}}$) and the average range ($\bar{R}$). These values are 7.126 and .0037, respectively. Following are the control limit calculations:

$$UCL_{\bar{x}} = \bar{\bar{x}} + A_2\bar{R} =$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - A_2\bar{R} =$$

$$UCL_R = D_4\bar{R} =$$

$$LCL_R = D_3\bar{R} =$$

In these calculations, the values of A_2, D_3, and D_4, are found in Appendix A. The row for subgroup size four is used because each hourly sample has four readings.

Xbar and R Control Chart Machine_____ Process_____

Product/Part name & number *mp plate w239* Gage *64e* Specification limits 7.125±.010

Date/Operator *3/17 Hoss*

Time		7am	8	9	10	11	noon	1pm	2	3	4		
	1	7.127	7.125	7.123	7.127	7.128	7.125	7.126	7.126	7.127	7.128		
	2	7.123	7.126	7.129	7.127	7.125	7.125	7.123	7.126	7.129	7.123		
	3	7.123	7.121	7.129	7.124	7.126	7.127	7.123	7.127	7.128	7.122		
	4	7.126	7.122	7.124	7.125	7.127	7.128	7.125	7.128	7.129	7.124		
	5												
Ave: $\overline{X}$		7.125	7.124	7.126	7.126	7.127	7.126	7.124	7.127	7.128	7.124		
Range, R		.004	.005	.006	.003	.003	.003	.003	.002	.002	.006		

Notes:

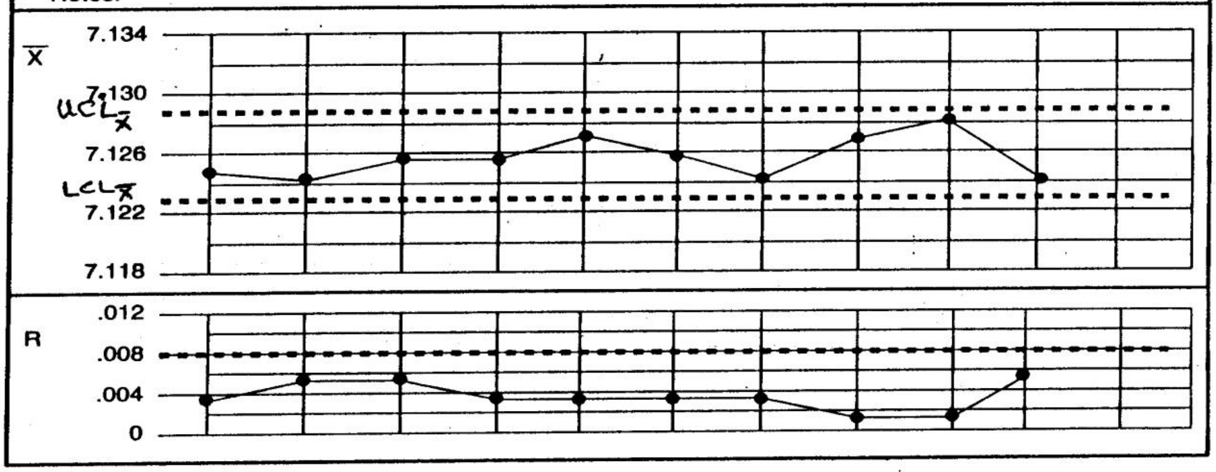


Figure VIII.5 Completed $\bar{X}$ and R control chart.

The next step is to choose a scale on the average and range charts that includes the control limits. The control limits are then drawn, usually with a dashed line, and the average lines are drawn on each chart, usually with solid lines. Finally, the points are plotted and connected with a broken line. The final chart is shown in Figure VIII.5.

$\bar{X}$ and s Control Charts

The $\bar{X}$ and s control chart is very similar to the $\bar{X}$ and R except that each value in the range row is replaced by the sample standard deviation, s. Calculation of control limits is very similar, also. Instead of using $\bar{R}$, these formulas use $\bar{s}$ and the appropriate constants from Appendix A:

Upper control limit for the averages chart: $\text{UCL}_{\bar{x}} = \bar{\bar{x}} + A_3 \bar{s}$

Lower control limit for the averages chart: $\text{LCL}_{\bar{x}} = \bar{\bar{x}} - A_3 \bar{s}$

Upper control limit for the standard deviation chart: $UCL_s = B_4 \bar{s}$

Lower control limit for the standard deviation chart: $LCL_s = B_3 \bar{s}$

An example of an $\bar{X}$ and s control chart is shown in Figure VIII.6, using the same data that were used in Figure VIII.5.

The formula calculations:

$$\text{UCL}_{\bar{x}} = \bar{\bar{x}} + A_3 \bar{s} =$$

$$\text{LCL}_{\bar{x}} = \bar{\bar{x}} - A_3 \bar{s} =$$

Upper control limit for the standard deviation chart: $UCL_s = B_4 \bar{s} =$

Lower control limit for the standard deviation chart: $LCL_s = B_3 \bar{s} =$

Individuals and Moving Range Control Charts

Recall that larger sample sizes produce more sensitive charts. In some situations, however, a sample size of 1 must be used. Examples include very slow processes or processes in which the measurement is very expensive to obtain, such as with destructive tests. If the sample size is 1, an Individuals and Moving Range (also known as ImR or XmR) chart is appropriate. An example of an ImR chart is shown in Figure VIII.7. The data are entered in the row numbered 1. The moving range is calculated by taking the absolute value of the difference between each measurement and the previous one. This value is entered in the row labeled Moving R.

The control limit formulas for the ImR control chart are:

$$\text{UCL}_x = \bar{x} + E_2 \overline{R}$$

$$\text{LCL}_x = \bar{x} - E_2 \overline{R}$$

$$\text{UCL}_r = D_4 \overline{R}$$

$$\text{LCL}_r = D_3 \overline{R}$$

The values of E_2, D_3, and D_4 are found in Appendix A. The sample size is 2 because two values were compared in each moving range.

The measurements in Figure VIII.7 have an average of 288 and an average range of 2.8.

Xbar and S Control Chart Machine_____ Process_____

Product/Part name & number ***mp plate w239*** Gage ***64e*** Specification limits 7.125±.010

Date/Operator ***3/17 Hoss***

Time		7am	8	9	10	11	noon	1pm	2	3	4		
	1	7.127	7.125	7.123	7.127	7.128	7.125	7.126	7.126	7.127	7.128		
	2	7.123	7.126	7.129	7.127	7.125	7.125	7.123	7.126	7.129	7.123		
	3	7.123	7.121	7.129	7.124	7.126	7.127	7.123	7.127	7.128	7.122		
	4	7.126	7.122	7.124	7.125	7.127	7.128	7.125	7.128	7.129	7.124		
	5												
Ave: $\overline{X}$		7.125	7.124	7.126	7.126	7.127	7.126	7.124	7.127	7.128	7.124		
Std Dev, s		.002	.002	.003	.002	.002	.002	.002	.001	.001	.003		

Notes:

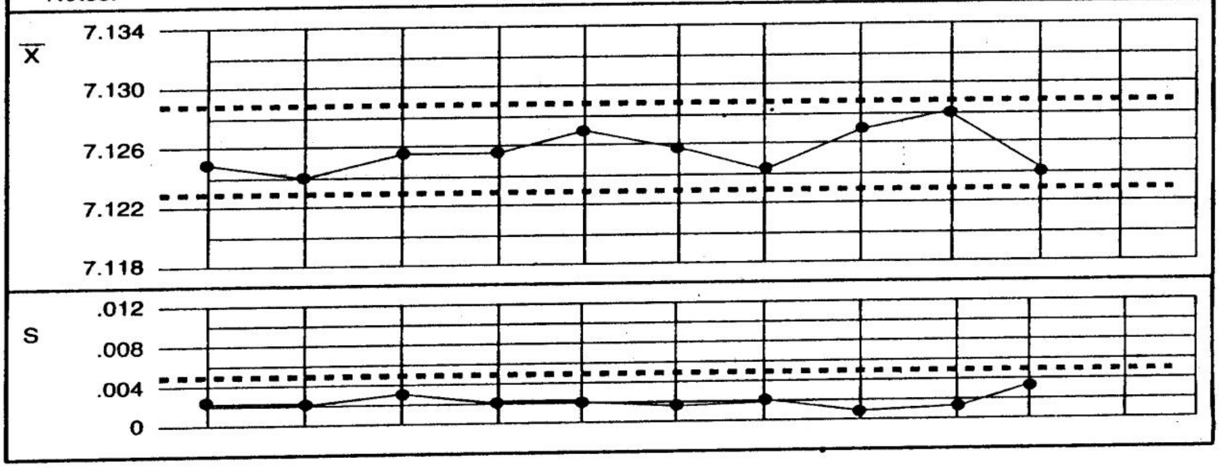


Figure VIII.6 Example of an $\overline{X}$ and s control chart.

$UCL_x =$

$LCL_x =$

$UCL_r =$

$LCL_r =$

These control limits are drawn and the measurements and ranges are then plotted.

Attribute Charts

Attribute charts are used for count data. The distinction between attribute and variables data is detailed in Section V.C.1. On attribute control charts, if every item is in one of two categories, such as good or bad, "defectives" are counted. If each item may have several flaws, "defects" are counted.

p Control Charts

The p chart is used to chart binary data where each item is in one of two categories. This would be the appropriate chart for plotting numbers of defectives, for instance. In the following example, each blood sample is in one of two categories, so the p chart is appropriate, although neither category is defective.

Example: A test for the presence of the Rh factor in 12 samples of donated blood yields the data shown on the p chart in Figure VIII.9.

Control limits for the p chart are given by the following formulas:

$$UCL = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{\bar{n}}}$$

$$LCL = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{\bar{n}}}$$

where

$$\bar{n} = \frac{\textit{Sum of the sample sizes}}{\textit{Number of samples}}$$

$$\bar{p} = \frac{\textit{Sum of the discrepencies}}{\textit{Sum of the sample sizes}} = \frac{\sum \textit{discrepencies}}{\sum n}$$

Note: When the formula for LCL produces a negative number, no LCL is used.

The control limit formulas use the average sample size. Some software packages recompute control limits each time the sample size changes. While technically correct, this is somewhat difficult when charts are being plotted by hand. As a compromise, the Automotive Industry Action Group (AIAG) recommends recalculating control limits whenever the sample is more than 25% above or below the average sample size.

In the example in Figure VIII.9:

$$\bar{n} = \frac{\text{Sum of the sample sizes}}{\text{Number of samples}} =$$

$$\bar{p} = \frac{\text{Sum of the discrepencies}}{\text{Sum of the sample sizes}} = \frac{\sum \text{discrepancies}}{\sum n}$$

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

$$\text{UCL} = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{\bar{n}}} =$$

$$\text{LCL} = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{\bar{n}}} =$$

np Control Charts

If defectives are being counted and the sample size remains constant, the np chart can be used instead of the p chart.

Example: Packages containing 1000 light bulbs are randomly selected and all 1000 bulbs are light-tested. The data are entered in the np chart in Figure VIII.10. Note that this chart is slightly simpler to use than the p chart because the number of defectives is plotted rather than the fraction of the sample. The formulas for control limits:

$$\text{UCL}_{np} = \overline{np} + 3\sqrt{\overline{np}\left(1 - \frac{\overline{np}}{n}\right)}$$

$$\text{LCL}_{np} = \overline{np} - 3\sqrt{\overline{np}\left(1 - \frac{\overline{np}}{n}\right)}$$

where

$\overline{np}$ = average number of defectives

n = sample size

Note: When the formula for LCL produces a negative number, no LCL is used.

For the example shown in Figure VIII.10, $\overline{np} = 120 \div 13 \approx 9.23$ and n = 1000.

$$\text{UCL}_{np} =$$

$$\text{LCL}_{np} =$$

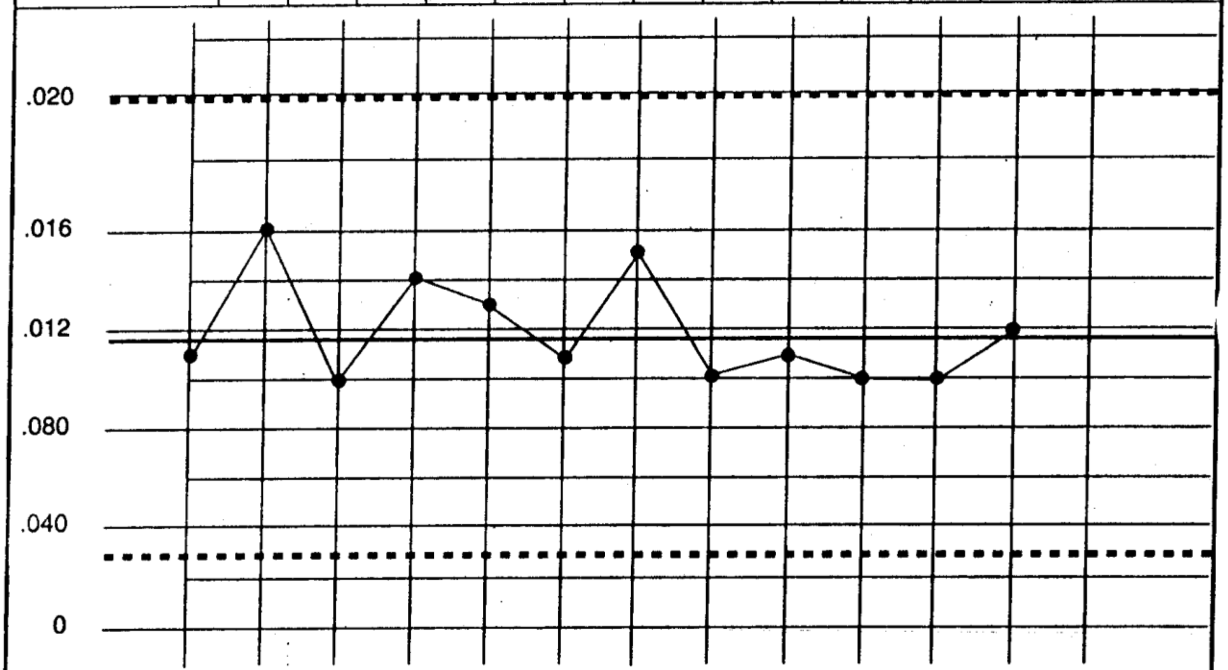
P Chart

Machine/Process ***Blood Analysis***

Product ***donated blood***

Defective = ***Rh negative***

Date 2002	*Sept. 8*	*8*	*8*	*8*	*9*	*9*	*12*	*12*	*12*	*12*	*12*	*12*	*12*		
Oper.	*Emily* ------						*Dana* ------								
Defectives, np	# 14	18	13	17	15	15	16	11	14	13	14	17			
Sample Size	125	111	133	120	118	137	108	110	124	128	144	138			
Fraction, p	.11	.16	.10	.14	.13	.11	.15	.10	.11	.10	.10	.12			



Notes:

Figure VIII.9 Example of a P chart.

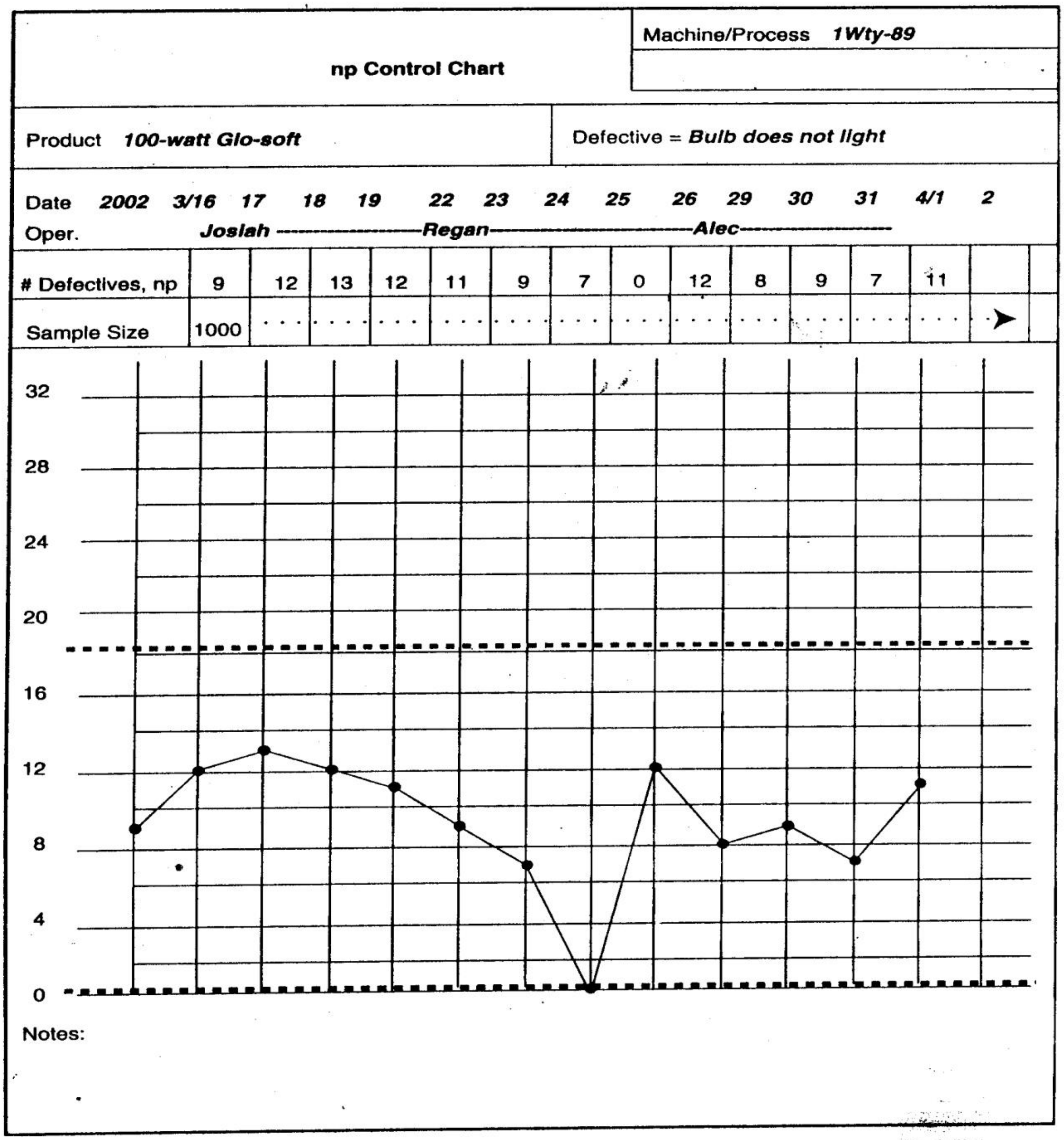


Figure VIII.10 Example of an np control chart.

u Control Charts

The u chart is appropriate for use when defects rather than defectives are counted. The example in Figure VIII.11 shows the results of inspecting panes of glass in which defects include bubbles, scratches, chips, inclusions, waves, and dips. The number of defects is counted and recorded for each sample, and the fraction (#defects) ÷ (sample size) is calculated and plotted.

The formulas for the control limits for the u chart:

$$\text{UCL} = \bar{u} + \frac{3\sqrt{\bar{u}}}{\sqrt{\bar{n}}}$$

$$\text{LCL} = \bar{u} - \frac{3\sqrt{\bar{u}}}{\sqrt{\bar{n}}}$$

where

$$\bar{u} = \frac{\sum defects}{\sum sample\ sizes}$$

$\bar{n}$ = average sample size

Note: When the formula for LCL produces a negative number, no LCL is used.

The control limit formulas use the average sample size. Some software packages recalculate control limits each time the sample size changes. While technically correct, this is somewhat difficult when charts are being plotted by hand. As a compromise, the Automotive Industry Action Group (AIAG) recommends recalculating control limits whenever the sample is more than 25% above or below the average sample size.

For the example in Figure VIII.11:

$$\bar{u} = 66 \div 1496 \approx 0.044$$

$$\bar{n} = 1496 \div 12 \approx 124.7$$

$$\text{UCL} = \bar{u} + \frac{3\sqrt{\bar{u}}}{\sqrt{\bar{n}}} =$$

$$\text{LCL} = \bar{u} - \frac{3\sqrt{\bar{u}}}{\sqrt{\bar{n}}} =$$

c Control Charts

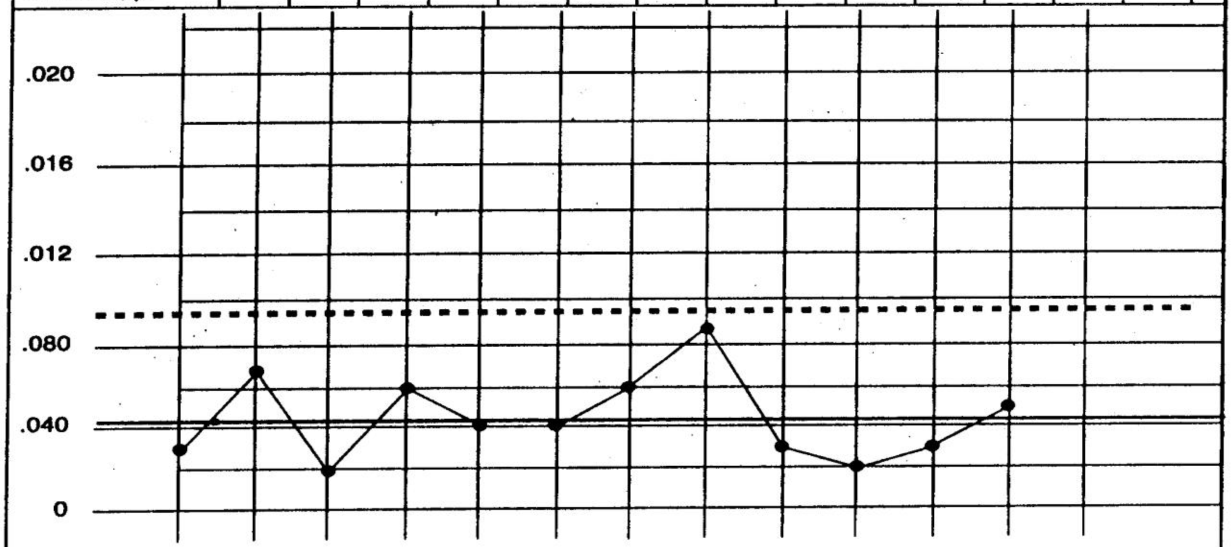
When defects are counted and the sample size is constant, the c chart may be used instead of the u chart. Note that this chart is slightly simpler to use than the u chart because the number of defects is plotted rather than the fraction of the sample. An example of a c chart is given in Figure VIII.12. The formulas for control limits:

U Chart	Machine/Process *float plate*
Product *Igapne 28x3*	Defective = *bubbles, scratches, chips, inclusions, waves, dips*

Date 2004 *Aug 8 8 8 8 9 9 12 12 12 12 12 12 12*

Oper. *Smith*——————————————————————

# Defects, u	4	8	3	7	5	5	6	10	4	3	4	7			
Sample Size	125	111	133	120	118	137	108	110	124	128	144	138			
Fraction, p	.03	.07	.02	.06	.04	.04	.06	.09	.03	.02	.03	.05			



Notes:

Figure VIII.11 Example of a u chart.

$$UCL = \bar{c} + 3\sqrt{\bar{c}}$$

$$LCL = \bar{c} - 3\sqrt{\bar{c}}$$

where

$\bar{c}$ = average number of defects

Note: When the formula for LCL produces a negative number, no LCL is used.

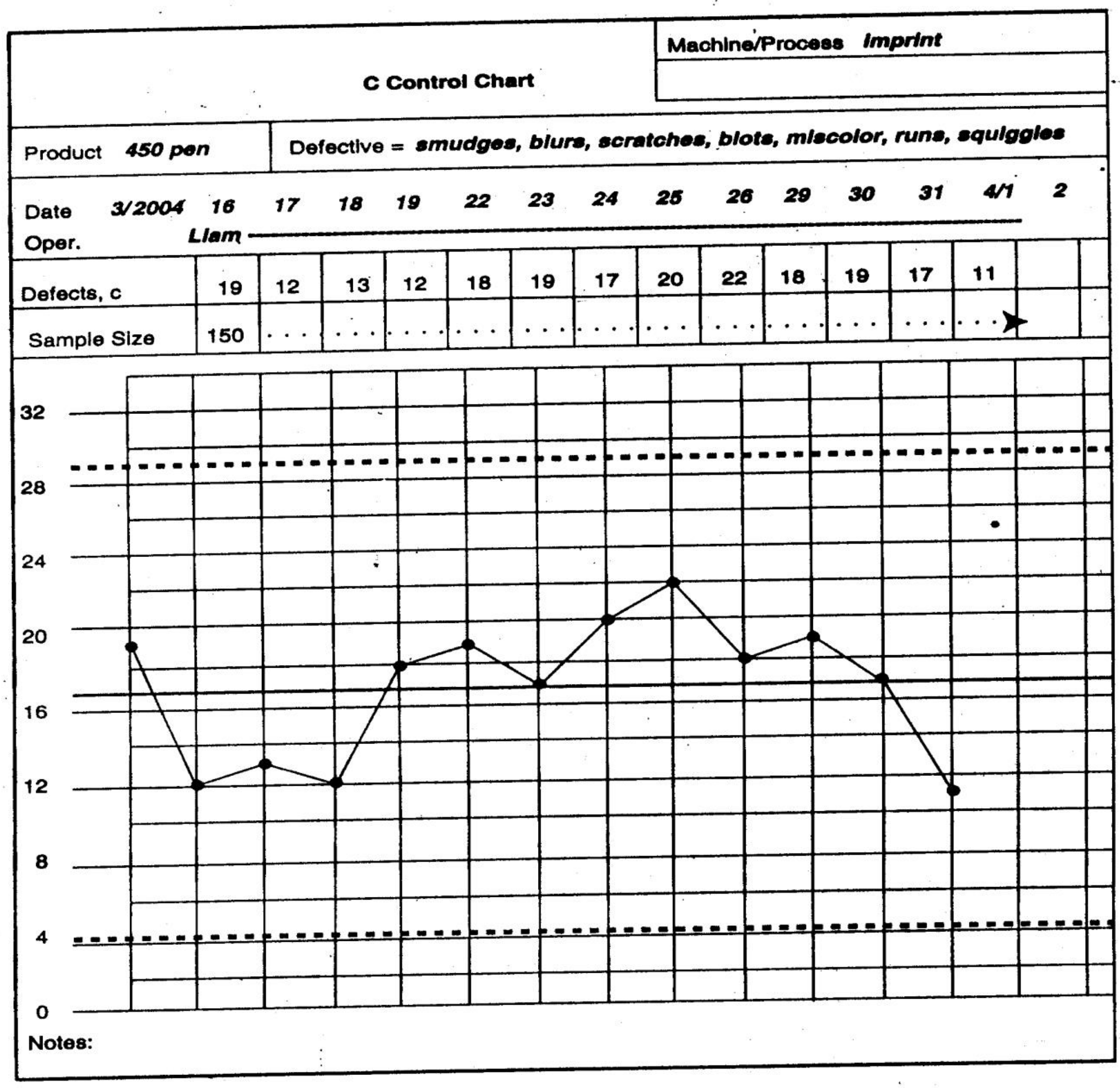


Figure VIII.12 Example of a c control chart.

For the example in Figure VIII.12, $\bar{c} =$

UCL =

LCL =

DECISION TREE FOR CHOICE OF CONTROL CHART

VARIABLE (CONTINUOUS) DATA			DISCRETE DATA			
SUB-GROUP SIZE = n			***SAMPLE SIZE = n***			
n < or = 10	**n > 10**	**n = 1**	**Defectives**		**Defects**	
X-bar – R Chart	**X-bar – Std. -Deviation Chart**	**X-bar – MR Chart (I– MR Chart)**	**“n” is <u>not</u> constant**	**“n” is constant**	**“n” is <u>not</u> constant**	**“n” is constant**
-----	**-----**	**-----**	**p-chart**	**np-chart**	**u-chart**	**c-chart**

Basis for the Xbar-R and Xbar-S charts:

The **CENTRAL LIMIT THEOREM** states that, regardless of the shape of the population the sampling distribution of the means is approximately normally distributed if the sample size is sufficiently large.

(If the population is normally distributed, a sample size of 10 may be sufficient. For a weird population distribution, a sample size of 30 would suffice).

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Appendix - A

Constants for Control Charts

Subgroup size										A2 for Median charts			
N	A2	d2	D3	D4	A3	c4	B3	B4	E2		A4	D5	D6
2	1.880	1.128	-	3.267	2.659	0.798	-	3.267	2.660	1.880	2.224	-	3.865
3	1.023	1.693	-	2.574	1.954	0.886	-	2.568	1.772	1.187	1.091	-	2.745
4	0.729	2.059	-	2.282	1.628	0.921	-	2.266	1.457	0.796	0.758	-	2.375
5	0.577	2.326	-	2.114	1.427	0.940	-	2.089	1.290	0.691	0.594	-	2.179
6	0.483	2.534	-	2.004	1.287	0.952	0.030	1.970	1.184	0.548	0.495	-	2.055
7	0.419	2.704	0.076	1.924	1.182	0.959	0.118	1.882	1.109	0.508	0.429	0.078	1.967
8	0.373	2.847	0.136	1.864	1.099	0.965	0.185	1.815	1.054	0.433	0.380	0.139	1.901
9	0.337	2.970	0.184	1.816	1.032	0.969	0.239	1.761	1.010	0.412	0.343.	0.187	1.850
10	0.308	3.078	0.223	1.777	0.975	0.973	0.284	1.716	0.975	0.362	0.314	0.227	1.809

Pre- control Chart

A pre-control chart is sometimes used in place of a control chart or until sufficient data is collected to construct a control chart.

An **important difference** between pre-control charts and control charts is that the upper and lower pre-control limits are calculated from the tolerance limits rather than from the process.

Thus the pre-control chart isn't statistical in the sense that the distribution of the current process is **not statistical** i.e. the current process isn't being compared with a historic distribution.

A fairly standard way to **construct the pre-control (PC) limits** is to multiply the value of the tolerance (USL – LSL) by 0.25. Then subtract the resulting value from the USL and LSL to form the UCL & LCL.

It means we start with Process Width = ½ Specification Width

The **main disadvantage** of the Pre-Control Chart is that it is not statistically based. There is controversy over the use of pre-control chart, with some experts stating that "Pre-control is a poor substitute for standard control charts and not recommended in practice".

HOW TO USE SPC TOOLS – EXAMPLES

(home-work reading)

APPLICATION EXAMPLES

Sr. No.	Items	Application	Remark
1.	**Histogram** Construction: a) No. of bars is approximately taken = square root of number of readings b) Width of each bar (Bin Range) = Range / No. of bars c) X- Axis represents data values for each bar d) Y-axis represents the count of readings in each bar	A) Summarizes Process Behavior (Distribution) i) **Process Centering:** Indicates "Process Average" e.g., Productivity, Profit should be as large as possible. (Cycle Time, impurities, wastage should be as low as possible) ii) **Spread:** Less the range (spread), lesser the process variation iii) **Shape of the distribution:** • Single peak is desired • A double or multiple peak shows that the data is coming from multiple sources, such as different suppliers or frequent machine adjustments. **(Bi-modal or Multi-modal Histogram is indicator of assignable causes).** **B) Histogram is very good for comparing different sources of variation such as:** • **Different machines** • **Different persons** • **Different processes** ***Like Histogram, which other tool can be used for same application?***	• Only applicable for **Variable / Continuous** data

2.	**Pareto Analysis**	A) Use of 80:20 principle – Vital Few / Trivial Many (e.g., two defects account for 80% of the effect). Essentially a tool for **prioritization.** B) We can compare Pareto Chart for different sources of variation: • Different Machines • Different People • Different Processes **C) USES OF PARETO IN DMAIC PHASES:** i) **Define:** * To decide scope / boundaries of the problem. * Also to find CTQs. ii) **Measure:** To find CTPs. iii) **Analyze:** To find vital-few root causes after a fishbone. iv) **Improve:** To show the "before" and "after" status after implementing the actions for improvement.	• Only applicable for **count data**.

3.	**Cause & effect (Fishbone Diagram)**	A) Brainstorming to find: i) Potential causes that are listed under separate heads like: • Men / Money / Machines / Method / Materials / Environment. **B)** Fishbone needs to be followed up with Pareto Analysis or Multi-voting to **short-list the vital-few causes.**	

4.	**Average & Range Chart** (Used for Variable Data – medium volumes subgroup size **<u>upto 10</u>**) **Average & Standard Deviation Chart** (Used for Variable Data – high volumes subgroup size **<u>> 10</u>**)	A) Interpretation: • Average chart represents process setting (location) • Range chart represents spread in the process ii) **First analyze Range Chart** (Std. Deviation Chart). Only if range chart is in control. iii) **Then analyze Average chart.** (If range chart is out of control, there is no need to interpret the average chart. First take actions to bring range chart in statistical control). **B) Applications:** **i) In Manufacturing:** • Mass Production Situations • Batch production (sub-groups are taken batch wise). E.g., in heat treatment process 5 samples from each batch are collected) **ii) In service Business:** For Call Centers, banks, etc. we can analyze • Time to respond to a call • Call handling time • Time to encash a cheque	

5.	**Individual & Moving Range Charts** **(Used for Variable Data)**	**A) Application:** i) Used when no. of data points are few: **For example:** • Profit per Quarter • Time taken to prepare balance sheet • Time taken to handle customer complaint • Temperature / Pressure in process plant ii) One observation is recorded per period. **B) Typical Applications:** **iii) Manufacturing:** • In continuous process industry to monitor process parameters like temperature, pressure, etc. **iv) Service Business** • Time taken to complete a software module • Time taken to quote for a project • Time taken to process a letter of credit • Monthly Expenses of Office • Monthly sales figures. C) Interpretation is similar as for Average & Range chart	

6.	p-chart and np-chart (Used for Attribute data)	**A) Interpretation:** Rules are same e.g: • Any point outside the control limit • 7 points on one side of the Central line and within control limits • 6 points, within control limits, but continuously increasing or decreasing B) In p / np-chart, **even a point below LCL needs to be analyzed** (to understand why the performance is so good" on a certain day. Then we could standardize the conditions to repeat the good performance on all days). **C) Applications:** **i) Manufacturing:** • Analysis of Rejections • Analysis of Re-works **ii) Service:** • Percentage of LCs amended • Quotation Conversion ratio • Percentage of Renewals lost in an insurance company • Percentage of calls not resolved • Percentage of trainees failed in a test • No. of milestones missed in a software project	

7.	**c-chart and u-chart** **(Used for count data)**	**A) Interpretation:** Same as p-chart / np-chart. **B) Application:** **i) Manufacturing:** • No. of breakdowns • No. of accidents • No. of NCs in an audit • No. of people absent in a day. **ii) Service:** • No. Of Errors in L/C • No. of Breakdowns • No. of calls not as per CTQ in an hour • No. of errors at teller counter in a days.	

LEAN TOOLS FOR CONTROL

MUDA, MURA, MURI

1. What is MUDA?

Muda means any wasteful activity or any obstruction to smooth flow of an activity

***** Activity = Work + Muda

* Expenditure = Cost + waste

That is, for each activity there is expenditure and every work there is a cost associated.

Any expenditure on the Muda is a waste!

Therefore, Less Muda = More happy clients (as it impacts the quality, cost and delivery of products and services).

2. What is MURA?

*** Mura = Inconsistencies in the system**

- Happens sometimes?
- Happens some places?
- Happens to some people?
- One part is ok; the other part is not ok?

STANDARDISATION OF POLICIES, PROCEDURES, AND PROCESSES LEADS TO ELIMINATION OF MURA.

3. What is MURI?

*** Muri = Physical Strain**

- Bend to work?
- Push hard?
- Poor Lighting?
- Unclean Air?
- Repeat tiring action?
- Wasteful walk?

PHYSICAL STRAIN REDUCES THE ENJOYABILITY AND EFFECTIVENESS OF A PROCESS. IT ALSO REDUCES EFFICIENCY.

EXERCISE : Typical Categories of Waste -

Waste is **often hidden within the daily routine**. Without a clear – cut framework, it is difficult to tell whether one should take the trouble to eliminate a particular kind of waste or not.

Waste Category	Nature of Waste	Type of Economy (Actions) Needed to Eliminate
Waiting	Delay in getting decisions from customer (or senior)	
Rejection	Producing defective products	
Facilities	Having idle machinery and break – downs, taking too long for setup	
Expenses	Using more resources to achieve a given output	
Manpower Costs	Excess man-hours than planned / required	

Design	**Supplying products with more functions than needed by customer**	
Talent	**Employing people for jobs that can be assigned to less skilled people**	
Creativity	**Losing time, ideas, and opportunities for improvement, by not involving people or not listening carefully**	
New-product run-up	**Delay in implementation**	

USE OF LEAN TOOLS IN SIX SIGMA

KAIZEN & 5S:

KAI = Change

ZEN = For the better

Kaizen can be defined as

- **The systematic**
- **Organized improvement of processes.**
- **By those who operate them.**
- **Using straight forward methods of analysis.**

Kaizen has its origin on Japan but it is practiced all over the world.

The NASA Langley Research Centre has expanded the definition and use of Kaizen to include personal and home life. **Kaizen means continuous improvement in personal life, home life and working life as a whole.**

As related to the workplace, **Kaizen means continual improvement involving managers and workers, customers and suppliers alike.**

Masaaki Imai introduced the concept to America in 1986 in his landmark book, **Kaizen – The Key to Japan's Competitive Success**. Imai, a graduate of Tokyo University in American Studies, Lived in the United States for five years. During the 1950s, working for the Japanese Productivity Centre in Washington-DC, his principal responsibility was to escort Japanese businessmen through major American plants so they could learn about " the secret of American productivity." From this work he compared the methods used by American and Japanese firms to increase productivity. He observed that:

The American or Western approach was to seek breakthrough improvements through innovation using high technology, massive capital investments and highly trained engineers.

The Japanese way was to involve both workers and managers in making small, low-cost improvements in the way work is done. Both management and workers find room for improvement every day.

Kaizen typically starts with studying the way workers perform their jobs. The aim of this analysis is to develop operator-level persons to recognize and make incremental improvements on a daily basis **"by those involved with the production process".**

It is based on seeking the:

"Wisdom of 10 employees rather than the knowledge of one expert".

Among the building blocks identified by lmai for the Kaizen process, most important are:

a) Elimination of waste.

b) Good housekeeping.

a) Elimination of waste:

If we consider value- adding activities as those activities that directly change materials and / or information into a product or service for which a customer is willing to pay, then:

- Examples of value – adding operations would be providing service to customers, e-mailing account-statements to customers, fabrication, machining, polishing, etc.
- Examples of non-value adding operations would include unnecessary transportation, re-work, over-inspection, generation of scrap, over-production, waiting for information / data, carrying excess inventory, etc.

Imai realized that a large percentage of the activities could be eliminated and product quality would still not suffer – rather both productivity and quality would actually increase.

By eliminating waste, a company can achieve substantial increases in both in efficiency and customer satisfaction.

Because it costs nothing, waste elimination is one of the easiest ways for a company to improve its operations.

Steps for Waste Elimination, would include:

- **Go to where the work is being performed (the Gemba).**
- Observe what is going on,
- Recognize waste,
- Take steps to eliminate it.

b) Good Housekeeping:

5-S is the foundation of Kaizen. All Kaizen implementation starts with applying the concept of 5-S.

If you want to get a first-hand idea of the productivity of an organization or its general work culture, just walk around its premises and observe the housekeeping practices – the way the floors are swept, the work tables organized, the tools and stationery stored, the machines and equipment cleaned and maintained personal items kept.

These often tell more the any financial statement. They are closely linked to the flow of activities, employees morale, product and service quality and inventory level.

An organization with good housekeeping practices is able to **control costs, foster greater safety, enhance customer satisfaction and reduce staff turnover.**

The basis for good housekeeping is the concept popularly known as 5 – S:

Use of 5 – S in Six Sigma Projects:

(Used in Improve Phase)

- **To reduce non-value-added cycle times due to movement, search time, ineffective use of floor space.**

- **To improve inventory management.**

- **To reduce accidents and improve working conditions.**

5S Description	Objective
Sorting Out (SIERI): (Separate out all that is unnecessary and eliminate it. To **sort and remove unnecessary items from the active working area**) **- Segregate necessary items from unnecessary items** - Remove what is not required - Decide on frequency of sorting	**- Saving Space** **- Improve Concentration**
Systematic Arrangement (SEITON): (To arrange necessary items in a neat proper manner so that they can be easily retrieved for use). - Arrange in order **- A Place for Every thing and Everything in it's Place (PEEP)**	**- Minimize Search Time** **- Retrieve Faster**
Spic and Span (SEISO): (To clean and inspect your workplace thoroughly so that there is no dust on the floor, machines and equipment). - Clean the work place / equipment **- Ensure –Tip Top condition.**	**- Inspecting for problems** **- Taking corrective actions, faster**

Standardization (SEIKETSU): **(To brainstorm and standardize the way of doing different tasks. Then develop SOPs and train people for same.)** - Working methodology **(procedures and work instructions)**	**- higher productivity** **- more consisitency**
Self Discipline (SHITSUKE): (To observe self – discipline through continuous practice). **- Be disciplined: form the habit**	**- Doing it Right first time and every time**

The implementation of the 5 - S concept is within the reach of any organization – private or public, manufacturing or service, large, medium-sized or multinational.

The **above five steps** to good housekeeping provide for more than a way to maintain order.

They provide a framework for performing maintenance checks and stimulating ideas for improvement.

They are the **foundation for more responsible behaviour** as they involve the responsibility and commitment of every member of the organization, from the top management to the shop floor worker.

The **ultimate goal of housekeeping** activities is to reduce cost and increase productivity: an organisation which applies 5S does not pass on the cost of non-value adding activities to the customer.

Visual Factory:

Failing to follow work instructions in detail is a common source of process variation. Hence, easily accessible and clearly illustrated work instructions are very important.

This is especially true in situations where cross-trained personnel flex into various workstations. Good lines, signs, and labels help ensure that the right component is at the right place and time, further reducing variation.

If the process operator's attention must be turned away from the process to manage material replenishment, poorer process control may result. Hence, the concept of a water-spider leads to lesser variation in the production output.

Kanban:

A system is best controlled when material and information flow into and out of the process in a smooth and rational manner. If process inputs arrive before they are needed, unnecessary confusion, inventory, and costs generally occur. If process outputs are not synchronized with downstream processes, the result is often delays, disappointed customers, and associated costs. A properly administered kanban system improves control by assuring timely movement of products and information.

Poka-yoke:

Poka-yoke activities, by devising methods that make some erroneous events impossible, further enable process control by automatically eliminating another source of variation. Example: A newly assigned press operator placed finished parts on a pallet with the incorrect orientation. The next operator didn't notice the difference, resulting in several hundred spoiled products. A fixture for the pallet now makes it impossible to stack mis-oriented parts.

Total Productive Maintenance:

In any situation where mechanical devices are used, the working state of those devices has an impact on the control of the process. If equipment deteriorates even subtly, the process output may be affected, often in unsuspected ways.

Standard Work:

Finding better ways of producing an ever more consistent product is the essence of process control. Standard work contributes to this effort by assuring that product flowing into a process has minimal variation and that there is a reduction in the variation caused by the process.

BALANCED SCORECARD

What is the Balanced Scorecard?

A **new approach to strategic management** was developed in the early 1990's by Drs. **Robert Kaplan (Harvard Business School) and David Norton**. They named this system the 'balanced scorecard'.

Recognizing some of the weaknesses and vagueness of previous management approaches, the balanced scorecard approach provides a clear prescription as to what companies should measure in order to 'balance' the financial perspective.

The balanced scorecard is a *management system* (not only a measurement system) that enables organizations to clarify their vision and strategy and translate them into action. It provides feedback around both the internal business processes and external outcomes in order to continuously improve strategic performance and results. When fully deployed, the balanced scorecard transforms strategic planning from an academic exercise into the nerve center of an enterprise.

Kaplan and Norton describe the innovation of the balanced scorecard as follows:

> "The balanced scorecard retains traditional financial measures. But **financial measures tell the story of past events, an adequate story for industrial age companies for which investments in long-term capabilities and customer relationships were not critical for success.** These financial measures are inadequate, however, for guiding and evaluating the journey that information age companies must make to create future value through investment in customers, suppliers, employees, processes, technology, and innovation."

Thus, the Balanced Scorecard is a **performance management approach that focuses on four indicators, to monitor progress towards the organization's strategic goals**. These indicators (or perspectives) are:

1. The Learning and Growth Perspective

This perspective includes employee training and corporate cultural attitudes related to both individual and corporate self-improvement.

In a knowledge-worker organization, ***people*** -- the only repository of knowledge -- are the main resource. In the current climate of rapid technological change, it is becoming necessary for knowledge workers to be in a continuous learning mode. Organizations often find themselves unable to hire new technical workers, and at the same time there is a decline in training of existing employees. **This is a leading indicator of 'brain drain' that must be reversed.**

Metrics can be put into place to guide managers in focusing training funds where they can help the most. In any case, learning and growth constitute the essential foundation for success of any knowledge-worker organization.

Kaplan and Norton emphasize that **'learning' is more than 'training'; it also includes things like mentors and tutors within the organization**, as well as that ease of communication among workers that allows them to readily get help on a problem when it is needed. It also includes technological tools; what the Baldrige criteria call "high performance work systems."

2. The Business Process Perspective

This perspective refers to internal business processes. **Metrics based on this perspective allow the managers to know how well their business is running, and whether its products and services conform to customer requirements (the mission).**

These metrics have to be carefully designed by those who know these processes most intimately; with our unique missions these are not something that can be developed by outside consultants.

In addition to the strategic management process, two kinds of business processes may be identified: a) mission-oriented processes, and b) support processes. Mission-oriented processes are the special functions and many unique problems are encountered in these processes. The support processes are more repetitive in nature, and hence easier to measure and benchmark using generic metrics.

3. The Customer Perspective

Recent management philosophy has shown an increasing realization of the importance of customer focus and customer satisfaction in any business. These are leading indicators: if customers are not satisfied, they will eventually find other suppliers that will meet their needs.

Poor performance from this perspective is thus a leading indicator of future decline, even though the current financial picture may look good.

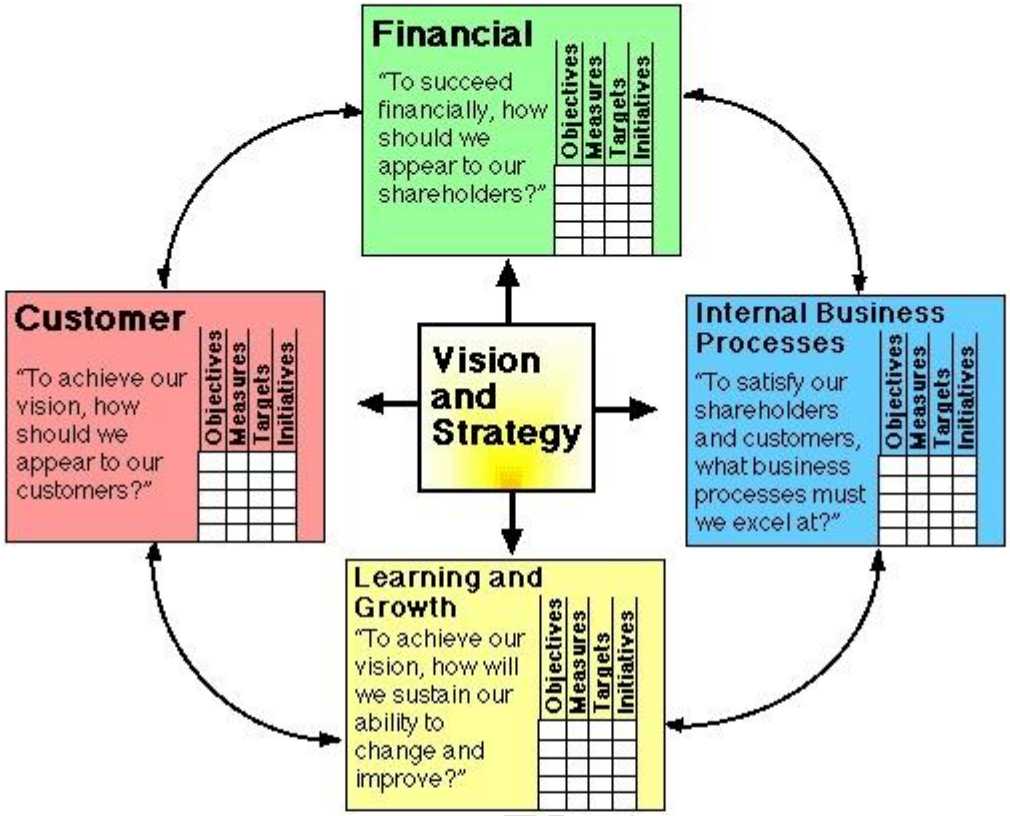
In developing metrics for satisfaction, customers should be analyzed in terms of kinds of customers and the kinds of processes for which we are providing a product or service to those customer groups.

4. The Financial Perspective

Kaplan and Norton do not disregard the traditional need for financial data. Timely and accurate funding data will always be a priority, and managers will do whatever necessary to provide it.

In fact, often there is more than enough handling and processing of financial data. With the implementation of a corporate database, it is hoped that more of the processing can be centralized and automated. But the point is that the current emphasis on financials leads to the "unbalanced" situation with regard to other perspectives.

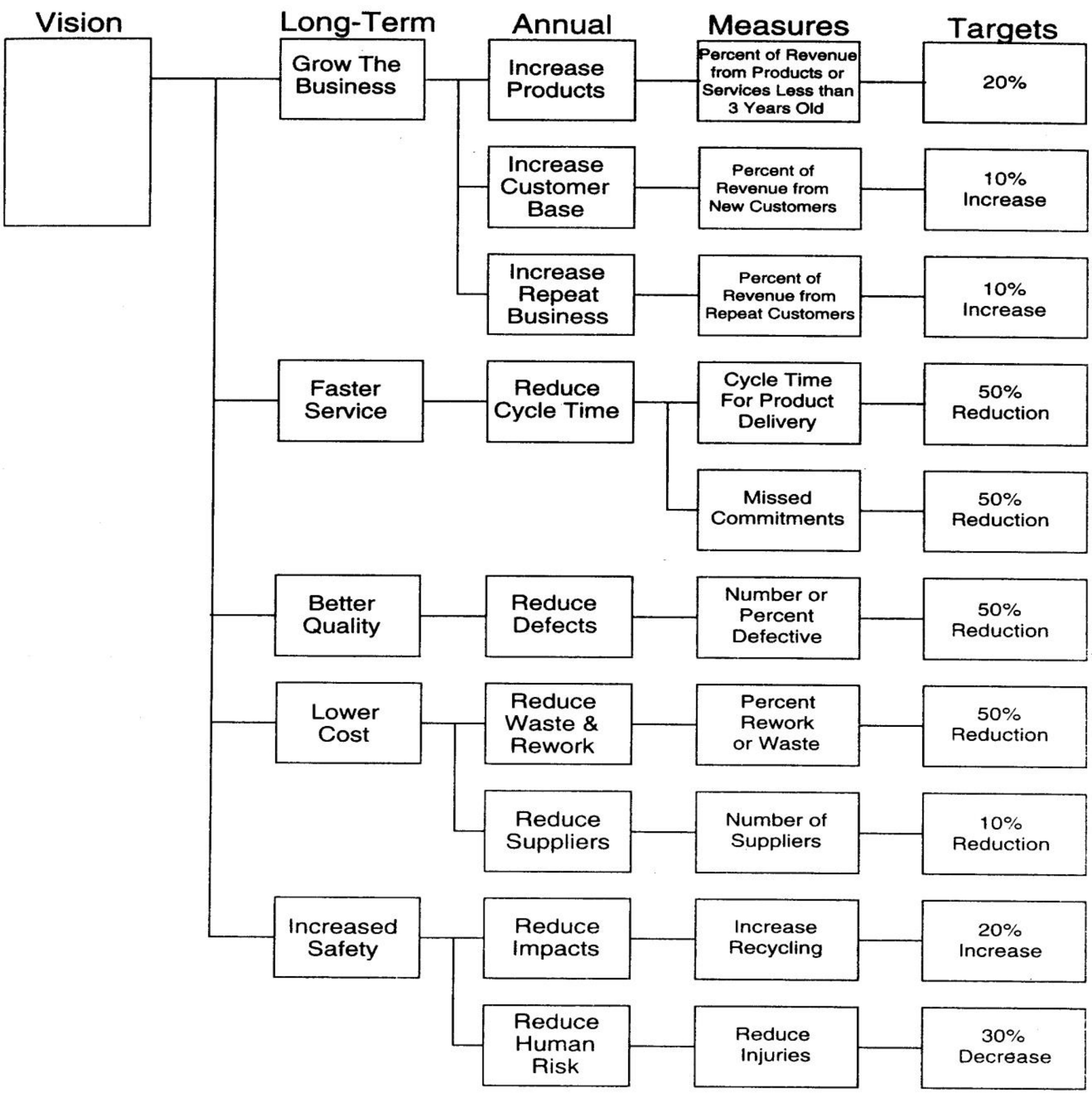
There is perhaps a need to include additional financial-related data, such as risk assessment and cost-benefit data, in this category.



The Balanced Scorecard and Measurement-Based Management

The balanced scorecard methodology **builds on some key concepts of previous management ideas such as Total Quality Management (TQM), including customer-defined quality, continuous improvement, employee empowerment, and -- primarily -- measurement-based management and feedback.**

Today, Lean Six Sigma methodology works hand in hand with the Balanced Scorecard approach.


Vision
Long-Term
Annual
Measures
Targets
Grow The Business
Increase Products
Percent of Revenue from Products or Services Less than 3 Years Old
20%
Increase Customer Base
Percent of Revenue from New Customers
10% Increase
Increase Repeat Business
Percent of Revenue from Repeat Customers
10% Increase
Faster Service
Reduce Cycle Time
Cycle Time For Product Delivery
50% Reduction
Missed Commitments
50% Reduction
Better Quality
Reduce Defects
Number or Percent Defective
50% Reduction
Lower Cost
Reduce Waste & Rework
Percent Rework or Waste
50% Reduction
Reduce Suppliers
Number of Suppliers
10% Reduction
Increased Safety
Reduce Impacts
Increase Recycling
20% Increase
Reduce Human Risk
Reduce Injuries
30% Decrease

Effective Strategic Management through the deployment of Lean Six Sigma with Balanced Scorecard

In today's **VUCA** (Volatile, Uncertain, Complex and Ambiguous) business environment, maintaining the competitive edge is a challenge for many organizations. Unlike the approach of basing strategic planning mainly on historical data, organizations need to adopt a more proactive path.

A **Balanced Scorecard** is a modern approach to Strategic Management that aligns an organization's activities to achieve its long term objectives. It measures long-term performance in terms of 4 perspectives:

- People perspective (Learning & Growth)
- Business process & Innovation perspective
- Customer satisfaction perspective
- Finance perspective.

It is called as balanced scorecard because it helps the management to focus on all the 4 perspectives leading to more proactive strategic management. **Using a balanced scorecard and lean six sigma together can be seen as an "ultimate" management solution**. A balanced scorecard can be used to identify the processes that are important and lean six sigma can be used to improve those processes.

Lean six sigma initiatives were first started as a powerful process improvement tool at Motorola in 1986 and gradually became the most popular process-excellence tool due to its organization-wide implementation by Jack Welch (GE Group) from 1995. **Today nearly 60% of the Fortune-500 companies, worldwide, use lean six sigma methodologies to achieve process excellence.**

Lean six sigma is a disciplined, data-driven methodology that uses the strength of cross-functional teams to eliminate defects and reduce variations, in any process - from manufacturing to transactional and from product to service. To reach a Six Sigma level of performance, a process must not produce more than 3.4 defects per million transactions.

The balanced scorecard is a framework for integrating performance measures defined by Robert Kaplan and David Norton in the 1990s. Many organizations are today implementing a balanced scorecard as their strategic management plan. The four perspectives of the balanced scorecard proposed by Kaplan and Norton, **as listed above**, provide a framework to describe the strategy for creating value and tools to manage the execution of that strategy. Balance scorecard helps us to identify performance gaps and is used to facilitate decisions on how to address specific performance issues. However, unlike lean six sigma, the balanced scorecard is not a solution for closing specific strategic performance shortfalls.

Balanced scorecard and lean six sigma become complementary because 'balanced scorecard' provides the strategic context for targeted improvement initiatives and 'lean six sigma' is a business improvement methodology that can solve hundreds of performance issues.

As an example, consider an organization that wants to increase sales turnover by 80% over the next 5 years. **The strategy for doing this requires:**

* Increase in number of products,

* Increase in number of customers,

* Increase in repeat business.

How will these be measured?

* Increase in the number of products can be measured in terms of revenue from new products. Based on this measurement, targets and action plans for the launch of new products during the next 5 years can be established.

* Increase in the number of customers can be measured in terms of revenue from new customers. Based on this measurement, targets and action plans for finding potential customers, and markets, during the next 5 years can be defined.

* Increase in repeat business can be measured in terms of revenues from repeat customers. Based on this measurement, targets and action plans for the retention of existing customers can be established.

In all these cases the analytical and cross-functional brain-storming tools of lean six sigma can be used to overcome road-blocks related to increasing the number of products, increasing the number of customers and achieving higher levels of customer retention. Increasing the number of products would require cross-functional collaboration between the Marketing, Design and Production functions to achieve holistic product development as per the established targets. Similarly, increasing retention of customers would require data analysis to identify the reasons for lost customers, the cross-functional collaboration between the Customer-service, Marketing & Production functions and training people to improve their people-management skills.

In short, a **balanced scorecard defines the strategy for creating value and planning the resources required for the successful execution of strategy. On the other hand, lean six sigma tools are used to implement the strategies** by using a variety of analytical and process improvement tools to achieve the long term targets as per the planned measurements

SIX SIGMA - A COMPLETE MANAGEMENT SYSTEM

1. Initially, Six Sigma was viewed as a set of problem-solving tools and process-improvement methodologies.

Today, Six Sigma has evolved into a practical management system for continual business improvement that helps the organization and its management to focus on five key areas:

a) Understanding and managing requirements of internal & external customers

b) Aligning key processes to achieve those requirements.

c) Using rigorous data analysis to understand and minimize variation in key process.

d) Driving rapid improvement to the business process

e) Ensuring that these improvement are sustained.

Leadership thru' Business Excellence

ASCB(E) Accrediting Certifying Bodies UK

2. Today's Six Sigma Management System is seen as consisting of four major components:

SIX SIGMA MANAGEMENT SYSTEM – FOUR PILLARS

BUSINESS PROCESS MANAGEMENT

In traditional Management ,the discrete functional departments form the building blocks.

In Six Sigma Management "business process" is treated as the fundamental building block.

The "business process" is the operational unit that is measured managed and continually improved.

TOP MANAGEMENT LEADERSHIP ROLE

Six Sigma is a top-down, leadership-driven business improvement system.

The Threefold challenge for the leadership is to:

a) Envision the future and establish strategic goals based on Q. C. S.

b) Draw out a roadmap to get there,

c) Communicate the roadmap and create a culture for implementing it.

The management uses the Balanced Scorecard framework for creating a strategic map consist of:

- Financial Objectives
- Learning & Growth Objectives
- Internal Business Process Objective
- Customer Satisfaction Objectives.

CROSS-FUNCTIONAL TEAMS (KAIZEN)

Deming & Juran have taught us that efforts of the quality function cannot focus only on technical improvements.

Six Sigma Management System requires cross-functional (boundary less) collaboration for improving the important processes in all areas of the organization.

Use of statistical techniques is one important tool.

Another aspect is the use of Kaizen (i.e. involvement of personally committed cross-functional teams for continual, and breakthrough, improvements).

DASHBOARD SYSTEM

Six Sigma System relies on collecting data and using the data as a base for strategic decision making.

Dashboard is a graphical display of critical indicators of the organization's current performance.

It allows leadership to track the progress of the organization towards meeting the strategic objectives.

BENCHMARKING METHODOLOGIES

BENCHMARKING METHODOLOGIES

1. Benchmarking is the **systematic search for best practices**, innovative ideas and highly effective operating procedures.

   It promotes superior performance by providing an original framework through which organizations:

   a) Learn how the “best in class” do things.

   b) Understand how these best practices differ from their own.

   c) Implement change to close the gap.

2. Benefits of Benchmarking :

a) It helps in **setting objectives based on the external environment** instead of looking only at our previous years’ “performance “.

b) It reduces the chances of **being caught unaware** by competition.

c) It is **time and cost efficient** because it involves imitation and adaptation rather than pure invention. (Saves the time and cost of re-inventing the wheel).

d) It **promotes innovation** because while looking at competition, we may hit upon some potential area for breakthrough improvement.

3. Techniques / Steps for Benchmarking :

a) Decide what to benchmark :

(i) Identify processes that are critical to success of the business.

(ii) Find which processes contribute most to customer satisfaction.

(iii) Find which processes are not performing upto expectations (or causing trouble)

(iv) Which of the competitive pressures are impacting the organize most ?

(v) Which processes have the potential to differentiate our organization from competition.

b) Understand current performance:

(i) Decide the units of measurement

(ii) Measure current performance in terms of these units such as unit cost, hourly rates, asset measures, quality measures, etc.

c) Plan :

(i) Select a benchmarking team

(ii) Decide :

- What type of benchmarking to perform.
- What type of data is to be collected.

- **What will be the method of data collection.**
- **By when the study will be completed.**

(iii) Benchmarking can be planned in 3 ways :

- **Internal comparisons with other departments / divisions.**
- **Comparison with competition through direct & indirect methods.**
- **Process benchmarking across industry boundaries.**
  e.g. Motorola looked to Dominos Pizza & Fedex for best ways to speed up delivery systems.

(d) Study Others:

All data need not be obtained through original research by site-visits & interviews. The options available include:

(i) Study internet sources & previous history.

(ii) Industrial data available in public domains (e.g. directories, magazines).

(iv) Competitors' distributors, dealers, franchisees.

(v) Focus groups (panels of customers, suppliers professional body members).

(vi) Questionnaires for data collection through mail, e-mail, phone, personal visits.

(e) Learn from the data:

We can learn from the data collected by asking following questions:

(i) Is there a gap between our performance and the best in-class?

(ii) What is the gap? How much is it?

(iii) Why is there a gap (root cause analysis)?

(iv) How does the "best –in-class" do it better than us?

(v) If best-in-class practices are adopted, what would be the resulting improvement?

(f) Use the findings:

The findings are used to define new objectives and action plans.
It includes steps like :

(i) Define the goals to be achieved.

(ii) Specify the tasks & decide their sequence.

(iii) Assign responsibility for each task.

(iv) **Describe check points at interim stages.**

(v) **Specify methods for monitoring the results**.

MEASUREMENT SYSTEM ANALYSIS

Measurement System Analysis for Service Businesses

1. Often MSA is a neglected step in service business since it is assumed that data is coming from an I. T. system and has to be accurate.

   In Six sigma, we view the measurement system also as a process:

X_1 = People gathering data →
X_2 = Tools (gages) used to gather data →
X_3 = Methods for recording data →
X_4 = Other Influences →
→ Y = Measurement

2. During Measure phase in DMAIC, we need to verify the measurement system because for any process.

Total observed = Variation from the measurement system + Variation from the process

(TV) = (MV) + (PV)

In MSA, our effort is to minimize MV

e.g.:We are measuring the "order cycle time" for the drive through lane in McDonalds.

Car Enters → Ordering + food pick up → Car leaves

Sensor records time T_E

Sensor records time T_L

So, we may say that cycle time = T_L - T_E is measured

very accurately by the system. Then why do we need MSA?

But, we need to look for variations in measurement that might enter due to the human intervention.

e.g. during peak times, car owners are requested to drive on and park on one side to allow the queue to move, while they wait for their parcel.

Does our measurement system take case of this factor?

3. In service business 2 pre – requisites are very important even before we go for MSA:

(a) Match the process output metric to the customer metrics:

Is the customer measuring process output in the same way as the supplier to the process?

e.g. Departure Time of aircraft:

Customer's Calculation	**Air lines Calculation**
From the point the aircraft doors are closed and it starts moving	**From the time when aircraft takes off from the runway.**

This measurement system on part of the airline ignores the "parking time" at some remote section of the tarmac.

So, the airline may show excellent punctuality which may not match with the customer satisfaction feedback.

(b) Operational Definitions:

An Operational definition is a specific – description of how the process output:

(i) will be measured
(ii) by whom
(iii) with what measurement tool
(iv) in what data – capture format

4. R & R Studies:

The Measurement System Variation	= Variation due to Repeatability (Equipment Variation)	+ Variation due to Reproducibility (Appraiser Variation)

(i) Equipment Variation (Repeatability Error):

Is the error when **one operator** uses the same measuring device / tool to measure the same element no. of times and obtains different results.

- **Solution for such errors - * Modify the measuring device**
  *** Improve the conditions for taking the readings (such as lighting, location, etc.)**

(ii) Appraiser Variation (Reproducibility Error):

Is the error when **multiple operators** use the same measuring device / tool to measure the same element multiple times and we get different results.

- **Solution for such errors - * Train the operators on understanding the operational definition and the measurement tool.**

- **M. S. A. for attribute data – A R & R**
- **M. S. A. for variable data – G R & R**

5. Attribute R & R:

(i) No. of operators measure a sample set 2 or more times.

(ii) We establish a standard (true level) and compare the operator's results with this level. (95 % or more matching is considered acceptable)

e.g. "Reason Code" form for

* Customer Complaints

* Product returns

* Help requests

Types of errors that may be discovered:

- Only few of the codes are used
- Some recently found reason may not have been coded, so people use different codes for same reason.

- Variation in understanding of the reason classification.

6. Gage R & R:

Similarly, we can do experiments to quantify the repeatability and reproducibility using variable data.

2 approaches are possible to calculate the percentage of variability due to the measurement system:

(i) Ratio of Measurement Variability to total Process variability. If this is less than 10 %, it is acceptable.

(ii) Calculating the G R & R as per standard methodology.

* **10 % or less is acceptable**

* **10 – 30 % is marginally acceptable.**

Example:

Cycle Time for processing customer orders was observed for 3 operators in respect of 10 orders. Same was video recorded.

Few days later, same process was repeated for the same orders (blind).
It was found that:

(i) Repeatability (same person) on same unit was small.

(ii) but Reproducibility (person to person differences) was much larger.

Further study showed the reasons for this variation as:

- 2 operators added time taken to pick up order from fax machine.
  But one operator started his stop watch after the order reached his desk.
- One person stopped the clock in case of any interruption. The other two did not.
- Time spent on seeking advice from another colleague was considered as part of the process by 2 persons but not by one person.

7. M S A for survey instruments:

A **pre – survey tested on about 20 persons is carried out to ensure that respondents understand same meaning of each question** as intended by the designer of the questionnaire.

Often gaps are found due to understanding of language and the questionnaire needs to be re-worded to remove such gaps.

Appendix- A: Examples of measurable CTQs in different processes

1. Human Resources:

(a) Absenteeism,
(b) Lost time due to accidents,
(c) Manpower Turnover,
(d) Employee satisfaction Index,
(e) No of suggestions for improvement,
(f) No of suggestions implemented,
(g) No of training hours per employee,
(h) No of grievances per month.

2. Customers:

(a) No. of complaints.
(b) No. of on – time deliveries / late deliveries.
(c) Warranty data (such as no. of parts replaced),
(d) Customer Satisfaction Index,
(e) Time to resolve complaints,
(f) Time to respond on telephone,
(g) Mean time to repair,
(h) Dealer Satisfaction Index.

3. Production:

(a) SPC Charts,
(b) Cp, Cpk,
(c) Amount of Scrap,
(d) Amount of Rework,
(e) Non-conformities per million units,
(f) Software errors per 1000 lines of code,
(g) % of flights that arrive on time,
(h) No. of items recalled from market,
(i) Cost per unit.

4. R & D:

(a) Average time to study proposals,
(b) Time taken to develop new products,
(c) Time taken to effect design changes,
(d) R & D spending to sales ratio,
(e) Product-recall data,
(f) Errors in Cost – Estimation.

5. Suppliers:

(a) SPC Charts,
(b) Cp, Cpk,
(c) No. of on-time deliveries,
(d) Service Rating,
(e) Quality Performance,
(f) Billing Accuracy,
(g) Average Lead Time.

6. Marketing / Sales:

(a) Sales Expense to Revenue,
(b) Order Accuracy,
(c) Introduction Cost to Development Cost,
(d) New-product sales to Total sales,
(e) No. of customers gained or lost per year,
(f) Sales income to no. of sales people,
(g) No of successful calls / week,
(h) External Failure Cost to Net Sales.

7. Administration:

(a) Revenue per employee,
(b) Cost of poor quality,
(c) No. of days accounts-receivable past due date,
(d) Office-equipment uptime,
(e) Errors in purchase orders,
(f) Vehicle fleet data,
(g) Billing Accuracy,
(h) Cost of Purchasing – Quality / Material Costs.

APPENDIX – B: CTQ METRICS

1. Many production processes are evaluated by their yield.

Yield is calculated for production applications by dividing the amount of product finishing the process by the amount of product that started the process.

For example, if 1,000 units started production, and of these 980 units successfully completed production, then the yield is calculated as 980 1000 = 98 %. The scrap rate refers to the units that could not be completed (in this case 2%)

2. Once the customer requirements have been determined, any process can be defined in terms of its yield.

For example, if 380 clients surveyed in a random sampling of 400 clients of a customer call center indicate that the service level is satisfactory, then the yield of the process can be calculated as 380/400 = 95%

3. A problem with the yield metric is that it does not provide enough detail of the nature of the errors.

E. g.:

- Process A: Of 4000 units started and 3800 completed, 200 defective units each had single defect, (95% yield)

- Process B: Of 4000 units started and 3800 completed, 200 defective units had total of 600 defects, (95% yield)
- Process C: Of 4000 units started and 3500 completed with no defects, 300 units reworked for 420 defects, 200 units scrapped for 580 defects, (95% yield)

These processes have different outcomes, yet the yield metric fails to discriminate between them.

In this production process, some units initially with errors can be reworked and sold as new. For example, units with unacceptable paint finish might be repaired and repainted. Likewise in a service process, a customer initially dissatisfied with the service may be directed to a manager for repair of the situation, resulting in an ultimately satisfied customer.

In terms of the metric, **if the reworked units are treated the same as non-reworked units,** information is lost. This simplistic yield metric hides the rework and process variation, resulting in increased process cycle times and costs.

1. **A solution to this limitation is offered in the throughput yield metric.**

Throughput yield measures the ability of the process to produce error-free units (or error- free service): the average percentage of units (or instances of service) with no errors.

Throughput yield (Y_t) is calculated by subtracting the defects per unit (DPU) percentage from 100 %

E.g. process A (described above) has a DPU of 200/4000 =5%, so its throughput yield is 95%.

For process B, DPU = 600 / 4000 = 15% and throughput yield = 85%

Finally, process C has a DPU of 1000/4000=25% (a throughput yield of 75%). In this case, the throughput yield is considerably less than the calculated first-pass yield.

5. Rolled throughput yield (Y_{rt}) is calculated as the expected quality level after multiple steps in a process.

If the throughput yield for n process steps is Y_{t1}, Y_{t2}, Y_{t3},..........Y_{tn}, then:

$Y_{rt} = Y_{t1} * Y_{t2} * Y_{t3} * \ldots * Y_{tn}$

E.g. Suppose there are six critical to quality steps required to process a customer order, with their throughput yields calculated as 0.997, 0.995, 0.95, 0.89, 0.923, 0.94, then rolled throughput yield is then calculated as:

$$\mathbf{Y_{rt} = 0.997 * 0.995 * 0.95 * 0.89 * 0.923 * 0.94 = 0.728}$$

Thus, **only 73 % of the orders will be processed error free.** Its interesting to see how much worse the rolled throughput yield is compared to the individual throughput yields.

6. As processes become more complex (i.e. more CTQ steps), **the combined error rates** can climb rather quickly. Hence, we should try to simplify processes to maximum extent.

7. Conversely, the **normalized yield** may be used as a baseline for process steps when a required rolled throughput yield is defined for the process series.

The normalized yield is calculated as the nth root of the rolled throughput yield.

E.g. if the desired rolled throughput yield is 90 % for a process with five steps, then the normalized yield for each step of the processes is $(0.90)^{1/5} = 0.98$ since 0.98 raised to the fifth power is approximately equal to 0.90.

The normalized yield provides the minimum throughput yield for each step of the process to achieve a given rolled throughput yield.

However, if some process steps cannot meet this normalized yield level, then the rolled throughput yield will be less.

APPENDIX- C: THEORY OF CONSTRAINTS

The theory of constraints is a problem-solving methodology that focuses on the weakest link in a chain of processes.

Usually the constraint is the process that is slowest.

Flow rate through the system cannot increase unless the rate at the constraint increases. Theory of constraints lists five steps to system improvement.:

a. Identify:

Find the process that limits the effectiveness of the system. If throughput is the concern, the constraint will be mostly at WIP (Work – In – Process)

b. Exploit:

Use kaizen or other methods to improve the rate of the constraining process.

c. Subordinate:

Adjust (or reduce) the rates of other processes in the chain to match that of the constraint.

d. Elevate:

If the system rate needs further increase, the constraint may require extensive revision (or elevation). This could mean investment in additional equipment or new technology, to achieve a breakthrough improvement.

e. Repeat:

If these steps have improved the process to the point where it is no longer the constraint, the system rate can be further improved by repeating these steps with a new constraint.

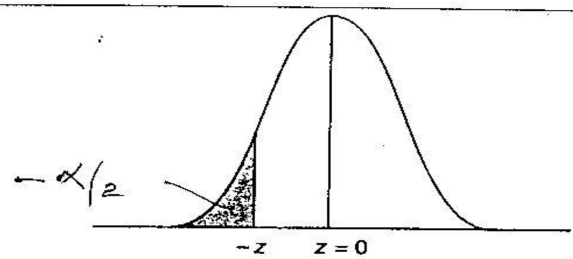
The strength of the theory of constraints is that it employs a systems approach, emphasizing that improvements to individual processes will not improve the rate of the system unless they improve the constraining process.

APPENDIX – D:
DISTRIBUTION TABLES

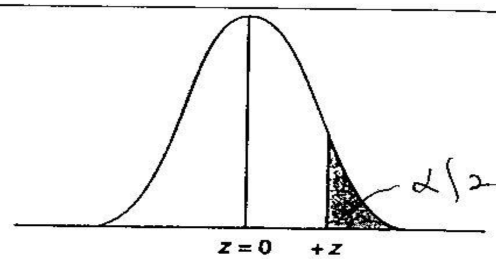
THE NORMAL DISTRIBUTION TABLE (TAIL AREA)

Appendix – 1

The normal distribution table



A negative z gives the left tail area.
Area = probability that a measurement is less than x.



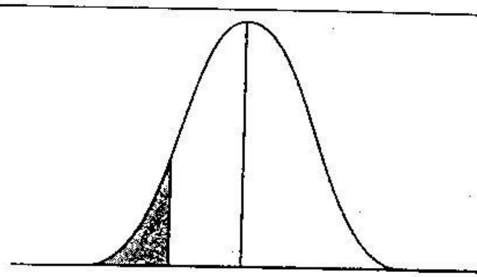
A positive z gives the right tail area.
Area = probability that a measurement is greater that x

$$z = \frac{x - \bar{\bar{x}}}{s}$$

|z|	0	1	2	3	4	5	6	7	8	9
0.0	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641
0.1	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
0.2	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
0.3	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
0.4	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
0.5	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
0.6	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
0.7	.2420	.2389	.2358	.2327	.2297	.2266	.2236	.2206	.2177	.2148
0.8	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
0.9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
1.4	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064

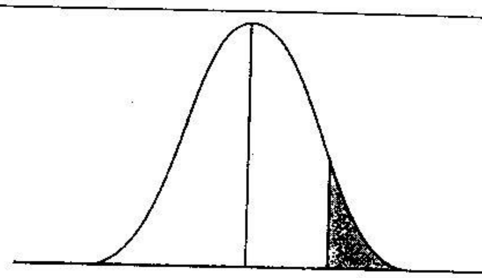
THE NORMAL DISTRIBUTION TABLE (TAIL AREA)

TABLE
continued



$-z$ $z = 0$

A negative z gives the left tail area.
Area = probability that a measurement is less than x.



$z = 0$ $+z$

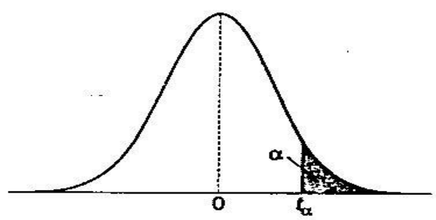
A positive z gives the right tail area.
Area = probability that a measurement is greater that x

$$Z = \frac{x - \bar{\bar{x}}}{s}$$

$\lvert z \rvert$	0	1	2	3	4	5	6	7	8	9
2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
2.9	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
3.0	.00135	.00131	.00126	.00122	.00118	.00114	.00111	.00107	.00104	.00100
3.1	.00097	.00094	.00090	.00087	.00084	.00082	.00079	.00076	.00074	.00071
3.2	.00069	.00066	.00064	.00062	.00060	.00058	.00056	.00054	.00052	.00050
3.3	.00048	.00047	.00045	.00043	.00042	.00040	.00039	.00038	.00036	.00035
3.4	.00034	.00032	.00031	.00030	.00029	.00028	.00027	.00026	.00025	.00024
3.5	.00023	.00022	.00022	.00021	.00020	.00019	.00019	.00018	.00017	.00017
3.6	.00016	.00015	.00015	.00014	.00014	.00013	.00013	.00012	.00012	.00011
3.7	.00011	.00010	.00010	.00010	.00009	.00009	.00008	.00008	.00008	.00008
3.8	.00007	.00007	.00007	.00006	.00006	.00006	.00006	.00005	.00005	.00005
3.9	.00005	.00005	.00004	.00004	.00004	.00004	.00004	.00004	.00003	.00003
4.0	.00003									

Appendix -2

Critical Values of the *t* Distribution



	α				
df	0.1	0.05	0.025	0.01	0.005
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.604
5	1.476	2.015	2.571	3.365	4.032

Continued on next page . . .

Appendices

Continued . . .

df	α 0.1	0.05	0.025	0.01	0.005
6	1.440	1.943	2.447	3.143	3.707
7	1.415	1.895	2.365	2.998	3.499
8	1.397	1.860	2.306	2.896	3.355
9	1.383	1.833	2.262	2.821	3.250
10	1.372	1.812	2.228	2.764	3.169
11	1.363	1.796	2.201	2.718	3.106
12	1.356	1.782	2.179	2.681	3.055
13	1.350	1.771	2.160	2.650	3.012
14	1.345	1.761	2.145	2.624	2.977
15	1.341	1.753	2.131	2.602	2.947
16	1.337	1.746	2.120	2.583	2.921
17	1.333	1.740	2.110	2.567	2.898
18	1.330	1.734	2.101	2.552	2.878
19	1.328	1.729	2.093	2.539	2.861
20	1.325	1.725	2.086	2.528	2.845
21	1.323	1.721	2.080	2.518	2.831
22	1.321	1.717	2.074	2.508	2.819
23	1.319	1.714	2.069	2.500	2.807
24	1.318	1.711	2.064	2.492	2.797
25	1.316	1.708	2.060	2.485	2.787
26	1.315	1.706	2.056	2.479	2.779
27	1.314	1.703	2.052	2.473	2.771
28	1.313	1.701	2.048	2.467	2.763
29	1.311	1.699	2.045	2.462	2.756
∞	1.282	1.645	1.960	2.326	2.576

Appendix -3

F Distribution $(\alpha = 1\%)$

$F_{.99}(n_1, n_2)$

= degrees of freedom for numerator $\quad n_2$ = degrees of freedom for denominator

n_2 \ n_1	1	2	3	4	5	6	7	8	9	10
1	4052	4999.5	5403	5625	5764	5859	5928	5982	6022	6056
2	98.50	99.00	99.17	99.25	99.30	99.33	99.36	99.37	99.39	99.40
3	34.12	30.82	29.46	28.71	28.24	27.91	27.67	27.49	27.35	27.23
4	21.20	18.00	16.69	15.98	15.52	15.21	14.98	14.80	14.66	14.55
5	16.26	13.27	12.06	11.39	10.97	10.67	10.46	10.29	10.16	10.05
6	13.75	10.92	9.78	9.15	8.75	8.47	8.26	8.10	7.98	7.87
7	12.25	9.55	8.45	7.85	7.46	7.19	6.99	6.84	6.72	6.62
8	11.26	8.65	7.59	7.01	6.63	6.37	6.18	6.03	5.91	5.81
9	10.56	8.02	6.99	6.42	6.06	5.80	5.61	5.47	5.35	5.26
10	10.04	7.56	6.55	5.99	5.64	5.39	5.20	5.06	4.94	4.85
11	9.65	7.21	6.22	5.67	5.32	5.07	4.89	4.74	4.63	4.54
12	9.33	6.93	5.95	5.41	5.06	4.82	4.64	4.50	4.39	4.30
13	9.07	6.70	5.74	5.21	4.86	4.62	4.44	4.30	4.19	4.10
14	8.86	6.51	5.56	5.04	4.69	4.46	4.28	4.14	4.03	3.94

Continued on next page . . .

Appendices

Continued...

$F_{.99}(n_1, n_2)$

n_1 = degrees of freedom for numerator n_2 = degrees of freedom for denominator

n_2 \ n_1	1	2	3	4	5	6	7	8	9	10
15	8.68	6.36	5.42	4.89	4.56	4.32	4.14	4.00	3.89	3.80
16	8.53	6.23	5.29	4.77	4.44	4.20	4.03	3.89	3.78	3.69
17	8.40	6.11	5.18	4.67	4.34	4.10	3.93	3.79	3.68	3.59
18	8.29	6.01	5.09	4.58	4.25	4.01	3.84	3.71	3.60	3.51
19	8.18	5.93	5.01	4.50	4.17	3.94	3.77	3.63	3.52	3.43
20	8.10	5.85	4.94	4.43	4.10	3.87	3.70	3.56	3.46	3.37
21	8.02	5.78	4.87	4.37	4.04	3.81	3.64	3.51	3.40	3.31
22	7.95	5.72	4.82	4.31	3.99	3.76	3.59	3.45	3.35	3.26
23	7.88	5.66	4.76	4.26	3.94	3.71	3.54	3.41	3.30	3.21
24	7.82	5.61	4.72	4.22	3.90	3.67	3.50	3.36	3.26	3.17
25	7.77	5.57	4.68	4.18	3.85	3.63	3.46	3.32	3.22	3.13
26	7.72	5.53	4.64	4.14	3.82	3.59	3.42	3.29	3.18	3.09
27	7.68	5.49	4.60	4.11	3.78	3.56	3.39	3.26	3.15	3.06
28	7.64	5.45	4.57	4.07	3.75	3.53	3.36	3.23	3.12	3.03
29	7.60	5.42	4.54	4.04	3.73	3.50	3.33	3.20	3.09	3.00
30	7.56	5.39	4.51	4.02	3.70	3.47	3.30	3.17	3.07	2.98
40	7.31	5.18	4.31	3.83	3.51	3.29	3.12	2.99	2.89	2.80
60	7.08	4.98	4.13	3.65	3.34	3.12	2.95	2.82	2.72	2.63
120	6.85	4.79	3.95	3.48	3.17	2.96	2.79	2.66	2.56	2.47
∞	6.63	4.61	3.78	3.32	3.02	2.80	2.64	2.51	2.41	2.32

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Appendix - 4

F Distribution ($\alpha = 5\%$)

$F_{.95}(n_1, n_2)$

n_1 = degrees of freedom for numerator $\quad$ n_2 = degrees of freedom for denominator

n_2 \ n_1	1	2	3	4	5	6	7	8	9	1[illegible]
1	161.4	199.5	215.7	224.6	230.2	234.0	236.8	238.9	240.5	24[illegible]
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38	19.40
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81	8.79
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00	5.96
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77	4.74
6	5.99	5.14	4.76	4.53	4.39	4.28	4.21	4.15	4.10	4.06
7	5.59	4.47	4.35	4.12	3.97	3.87	3.79	3.73	3.68	3.64
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39	3.35
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18	3.14
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02	2.98
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90	2.85
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80	2.75
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71	2.67
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65	2.60

Continued on next page . . .

Continued . . .

$F_{.95}(n_1, n_2)$

n_1 = degrees of freedom for numerator n_2 = degrees of freedom for denominator

n_2 \ n_1	1	2	3	4	5	6	7	8	9	10
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59	2.54
16	4.49	3.63	3.24	3.01	2.85	2.74	2.66	2.59	2.54	2.49
17	4.45	3.59	3.20	2.96	2.81	2.70	2.61	2.55	2.49	2.45
18	4.41	3.55	3.16	2.93	2.77	2.66	2.58	2.51	2.46	2.41
19	4.38	3.52	3.13	2.90	2.74	2.63	2.54	2.48	2.42	2.38
20	4.35	3.49	3.10	2.87	2.71	2.60	2.51	2.45	2.39	2.35
21	4.32	3.47	3.07	2.84	2.68	2.57	2.49	2.42	2.37	2.32
22	4.30	3.44	3.05	2.82	2.66	2.55	2.46	2.40	2.34	2.30
23	4.28	3.42	3.03	2.80	2.64	2.53	2.44	2.37	2.32	2.27
24	4.26	3.40	3.01	2.78	2.62	2.51	2.42	2.36	2.30	2.25
25	4.24	3.39	2.99	2.76	2.60	2.49	2.40	2.34	2.28	2.24
26	4.23	3.37	2.98	2.74	2.59	2.47	2.39	2.32	2.27	2.22
27	4.21	3.35	2.96	2.73	2.57	2.46	2.37	2.31	2.25	2.20
28	4.20	3.34	2.95	2.71	2.56	2.45	2.36	2.29	2.24	2.19
29	4.18	3.33	2.93	2.70	2.55	2.43	2.35	2.28	2.22	2.18
30	4.17	3.32	2.92	2.69	2.53	2.42	2.33	2.27	2.21	2.16
40	4.08	3.23	2.84	2.61	2.45	2.34	2.25	2.18	2.12	2.08
60	4.00	3.15	2.76	2.53	2.37	2.25	2.17	2.10	2.04	1.99
120	3.92	3.07	2.68	2.45	2.29	2.17	2.09	2.02	1.96	1.91
∞	3.84	3.00	2.60	2.37	2.21	2.10	2.01	1.94	1.88	1.83

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