

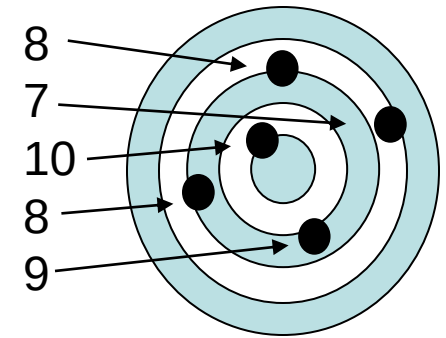
Level 5 – Continuous Improvement with Industry 4.0

Measure 4 – Variation, Capability recap and OEE

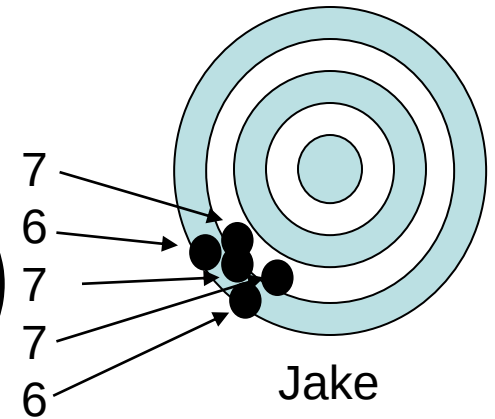


Deviation

**distance between
observations and
the mean *(or average)***

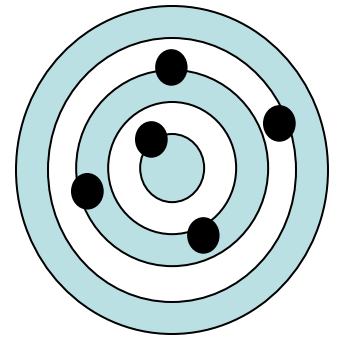


Fred

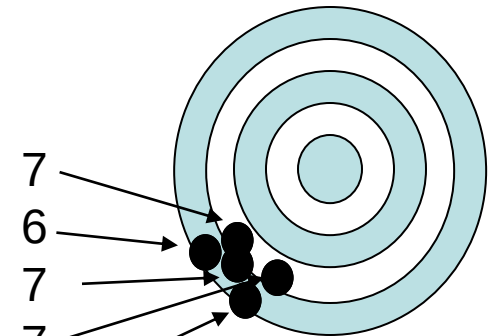


Jake

- Variance = average distance between observations and the mean squared



Fred



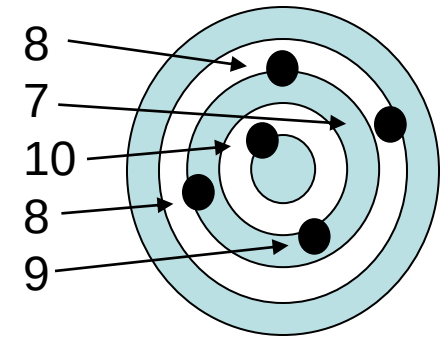
Jake

	Observations	Deviations	Squared Deviations
	7	$7 - 6.6 = 0.4$	0.16
	7	$7 - 6.6 = 0.4$	0.16
	7	$7 - 6.6 = 0.4$	0.16
	6	$6 - 6.6 = -0.6$	0.36
	6	$6 - 6.6 = -0.6$	0.36
averages	6.6		0.24

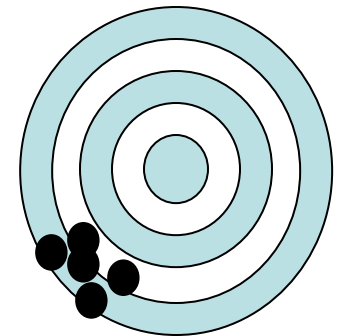
7
6
7
7
6

← Variance

- Variance = average distance between observations and the mean squared



Fred



Jake

	Observations	Deviations	Squared Deviations
	10	$10 - 8.4 = 1.6$	2.56
	9	$9 - 8.4 = 0.6$	0.36
	8	$8 - 8.4 = -0.4$	0.16
	8	$8 - 8.4 = -0.4$	0.16
	7	$7 - 8.4 = -1.4$	1.96
averages	8.4		1.0

← **Variance**

Measure - Standard Deviation

Consider a sample of 5 data points; 6.5, 7.5, 8.0, 7.2, 6.8

The **Range** is the highest minus the lowest; $8.0 - 6.5 = 1.5$

The **Mean** (X-bar) is 7.2

The Standard Deviation is

$$stdev = \sqrt{\frac{(6.5 - 7.2)^2 + (7.5 - 7.2)^2 + (8.0 - 7.2)^2 + (7.2 - 7.2)^2 + (6.8 - 7.2)^2}{5 - 1}}$$

$$stdev = 0.59$$

Fortunately, we have Excel!

Measure - Standard Deviation

Consider a sample of 5 data points; 6.5, 7.5, 8.0, 7.2, 6.8

The Standard Deviation is

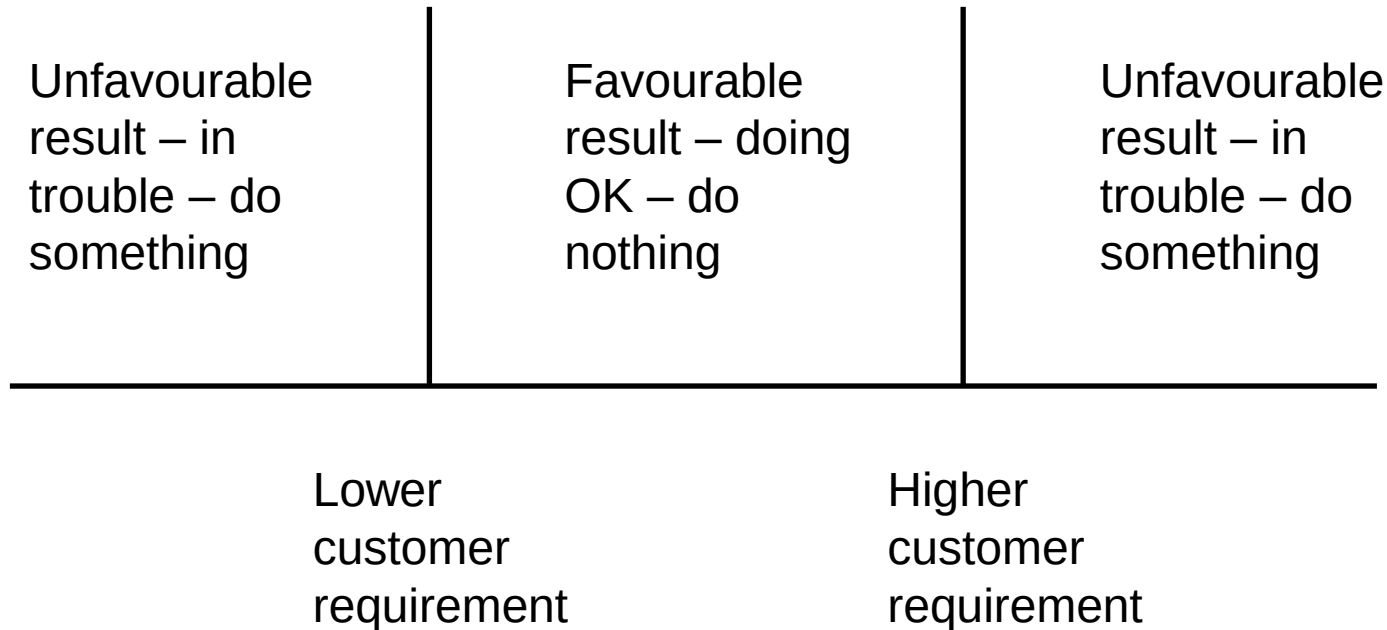
$$stdev = \sqrt{\frac{(6.5 - 7.2)^2 + (7.5 - 7.2)^2 + (8.0 - 7.2)^2 + (7.2 - 7.2)^2 + (6.8 - 7.2)^2}{5 - 1}}$$

Note The above n-1 is used when taking a sample from a population.

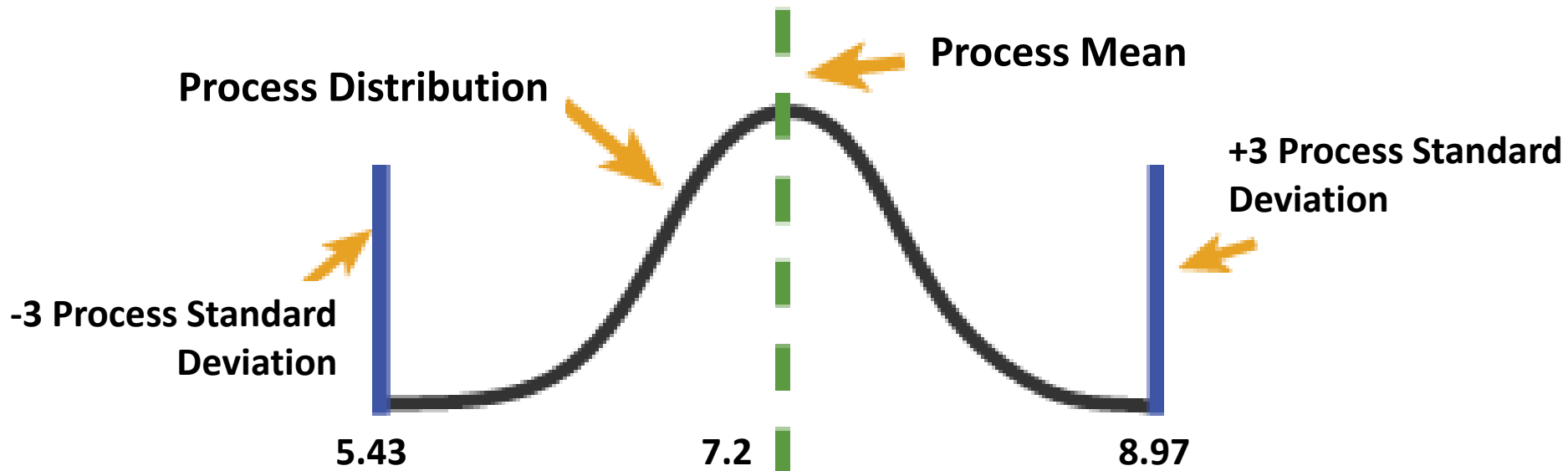
**You can use n if you are sure the data is the whole population
i.e arrows shot into target**



The Specification Value approach (VoC)

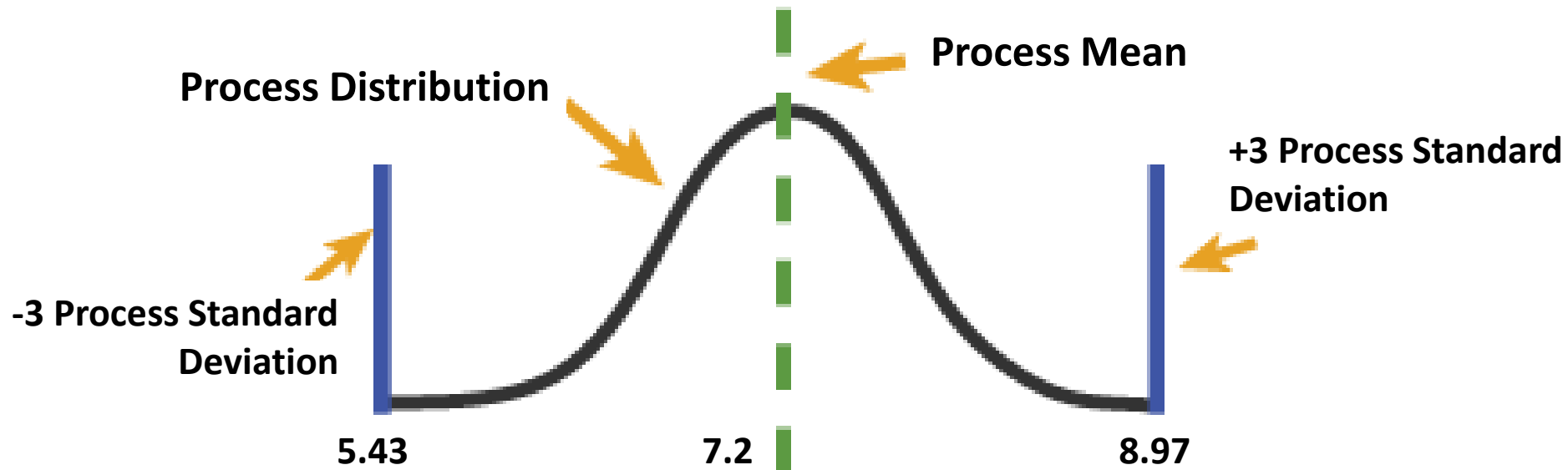


- Statistical tables have been developed for various types of distributions that quantify the area under the curve for a given number of standard deviations from the mean.
- Shewhart found that control limits placed at three standard deviations from the mean in either direction provide an economical trade-off between the risk of reacting to a false signal and the risk of not reacting to a true signal.



- We want to calculate three-sigma, which is three standard deviations above the mean.
- $3 \times \text{STDEV} + \text{Mean}$
- ***stdev* = 0.59**
→ $(3 \times 0.59) + 7.2 = 8.97$

- The illustration below shows a normal curve for a distribution with a mean of 7.2, a mean less 3 standard deviations value of 5.43, and a mean plus 3 standard deviations value of 8.97. Values, or measurements, less than 5.43 or greater than 8.97 are extremely unlikely.
- These laws of probability are the foundation of the control chart.

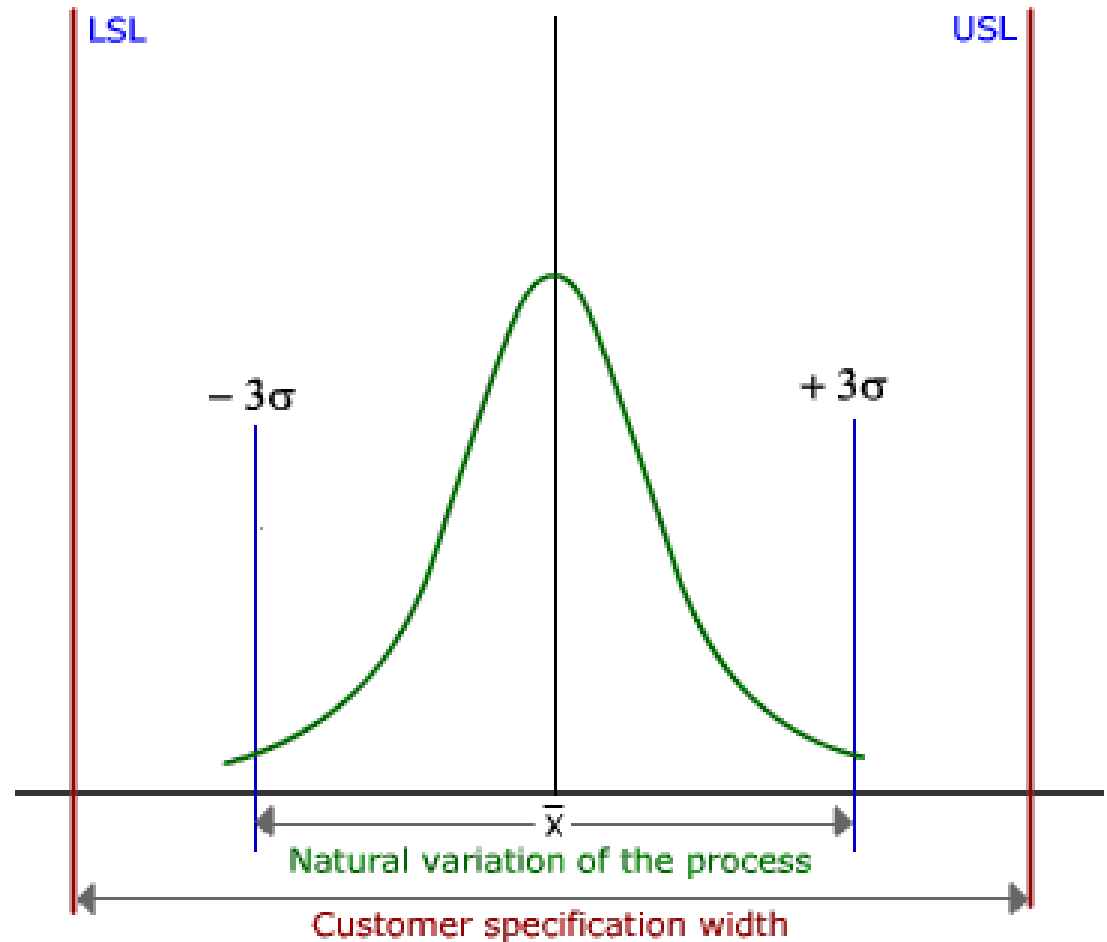


Control limits, are the 'Voice of the Process' Identified as;

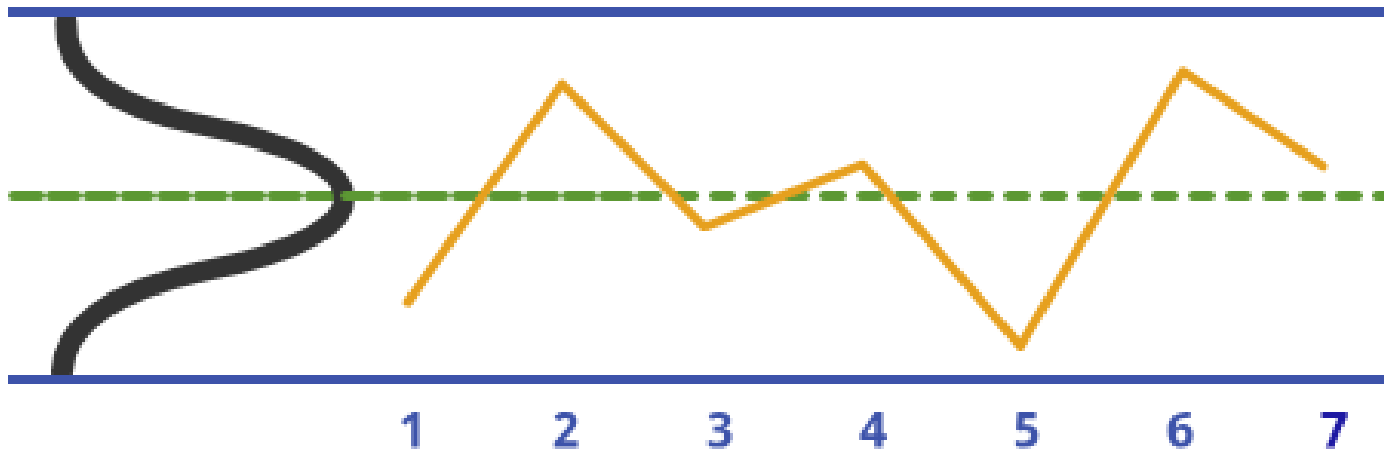
- Upper and Lower Control Limits

Tolerances are part of the Customer specification, and therefore the 'Voice of the Customer' Identified as;

- Upper and Lower Specification Limits (LSL & USL)



- Consider that the distribution is turned sideways, and the lines denoting the mean and ± 3 standard deviations are extended.
- This construction forms the basis of the Control chart.
- Time series data plotted on this chart can be compared to the lines, which now become control limits for the process.
- Comparing the plot points to the control limits allows a simple probability assessment.



Robust method on deciding when to take samples:-

- Random sampling – nos 4,17,22,24,32,43,57,68 etc
- Sequential sampling – 5 samples per hour, every hour

Two worst ways to take samples:-

- Judgement – based on someone's knowledge of process
- Convenience – easiest to measure or at convenient times

- Larger samples are more accurate
- Sample costs money, but so does being out-of-control
- Don't convert measurement data to "yes/no" binomial data
- Don't combine data (or mix product)
- Have out-of-control procedures (what do I do now?)
- Actual production volume matters (Average Run Length)

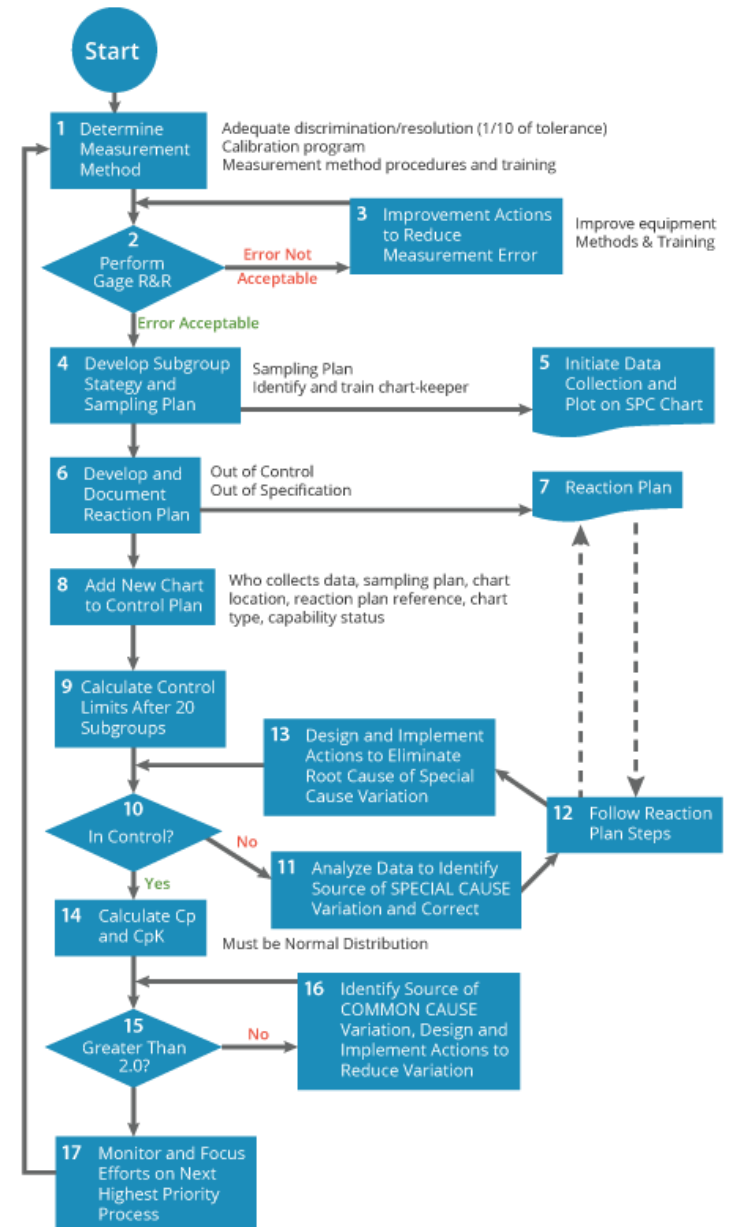
Rough sample size guidelines:-

- Variable data minimum 25 to 30 measurements
- Attribute data 50 to 100 samples
- We can understand optimizing sample sizes during 'Analyse' phase



Implementing Statistical Process Control

- Deploying Statistical Process Control is a process in itself, requiring organizational commitment across functional boundaries.
- The flow-chart below outlines the major components of an effective SPC effort.

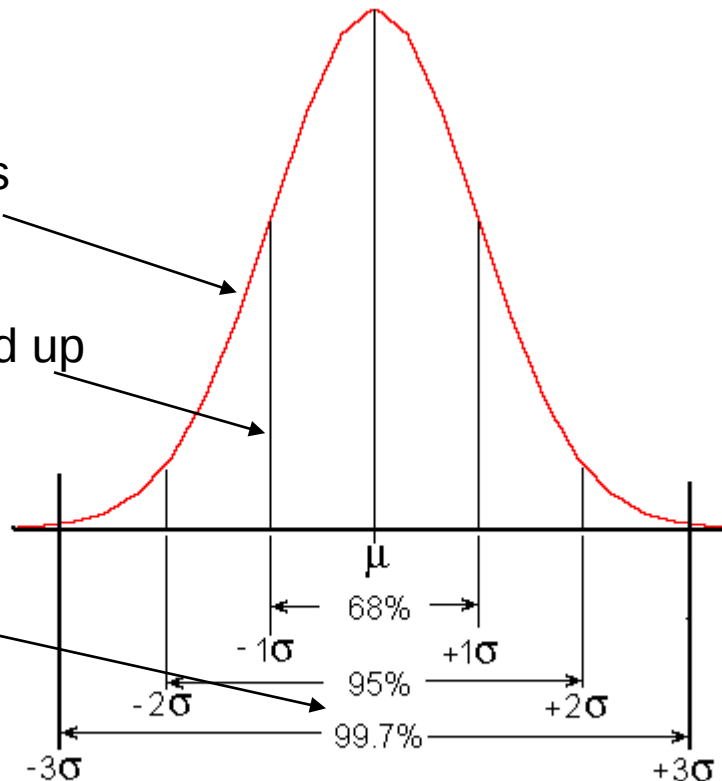


“Normal data” bell shaped curve

Add up about 30 of most things
and you start to be “normal”

Normal distributions are divided up
into 3 standard deviations on
each side of the mean

Once you have that, you
know a lot about
what is going on



And that is what a standard deviation
is good for

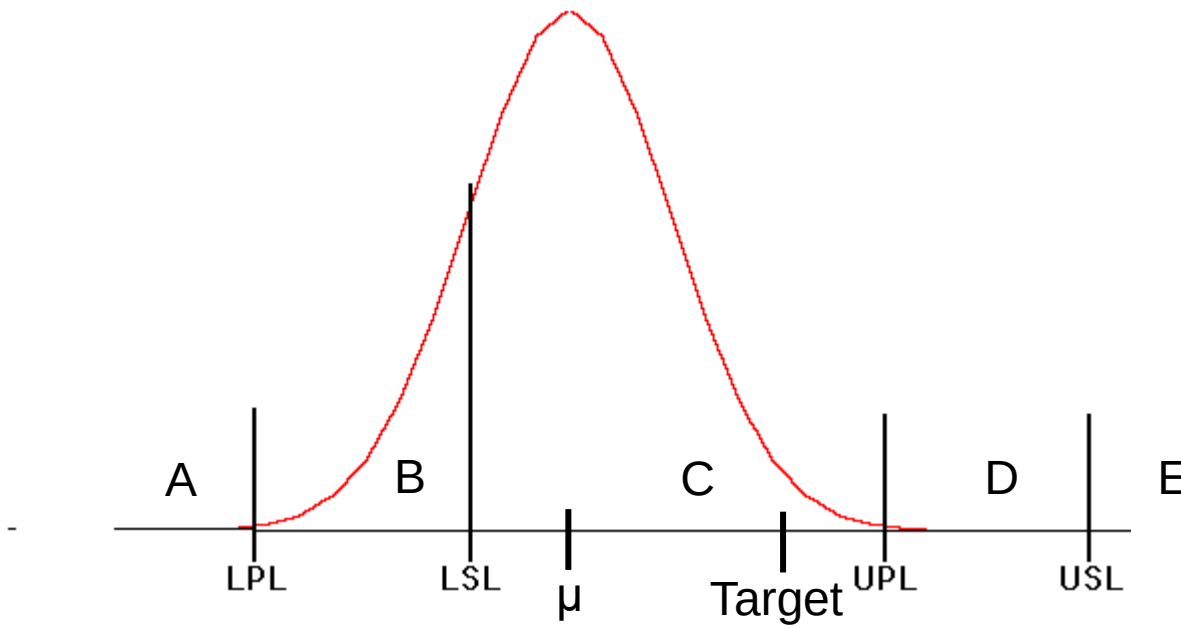


- Common Causes:
 - Random variation (usual)
 - No pattern
 - Inherent in process
 - adjusting the process increases its variation
- Special Causes
 - Non-random variation (unusual)
 - May exhibit a pattern
 - Assignable, explainable, controllable
 - adjusting the process decreases its variation

SPC uses samples to identify that special causes have occurred

- Process and Control limits (VoP):
 - Statistical
 - Process limits are used for individual items
 - Control limits are used with averages
 - Limits = $\mu \pm 3\sigma$
 - Define usual (common causes) & unusual (special causes)
- Specification limits (VoC):
 - Engineered
 - Limits = target $\pm$ tolerance
 - Define acceptable & unacceptable

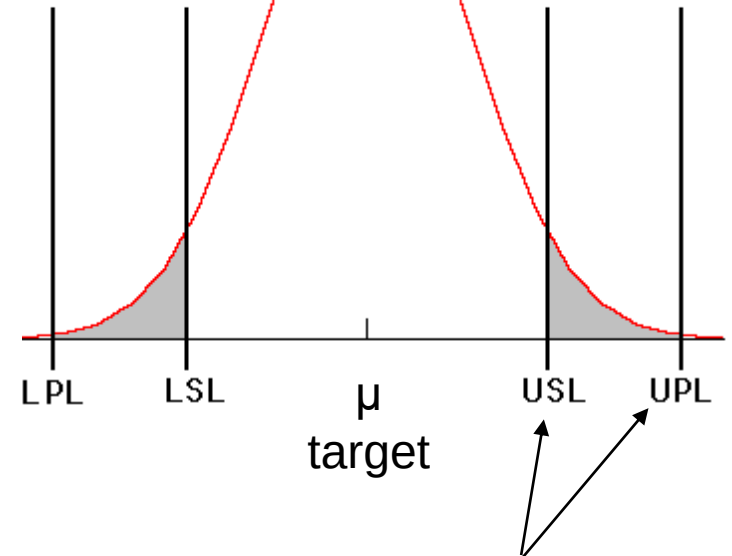
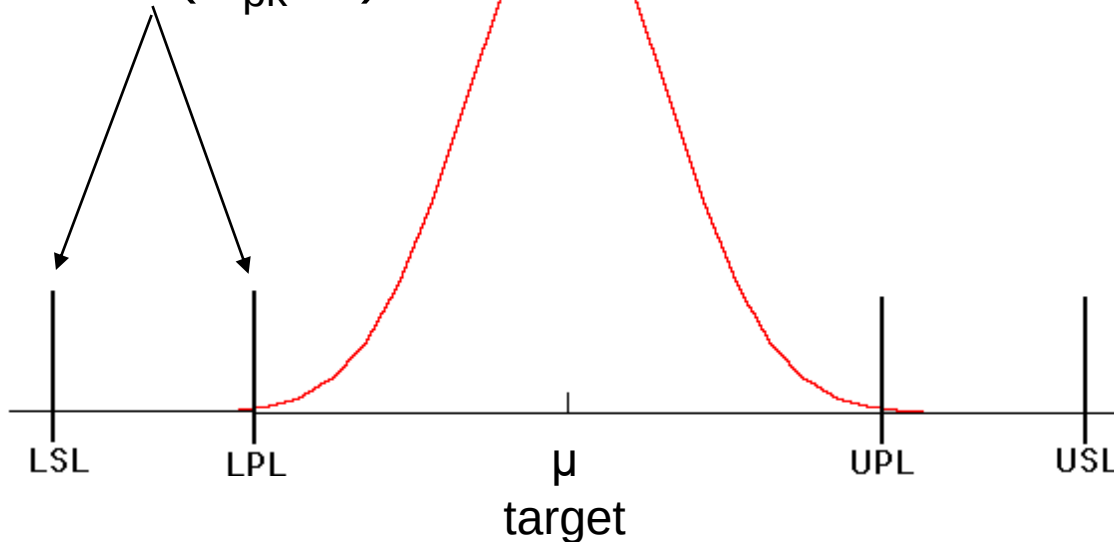
Usual v. Unusual, Acceptable v. Defective



More about limits



Good quality:
defects are
rare ($C_{pk} > 1$)



Poor quality:
defects are
common ($C_{pk} < 1$)

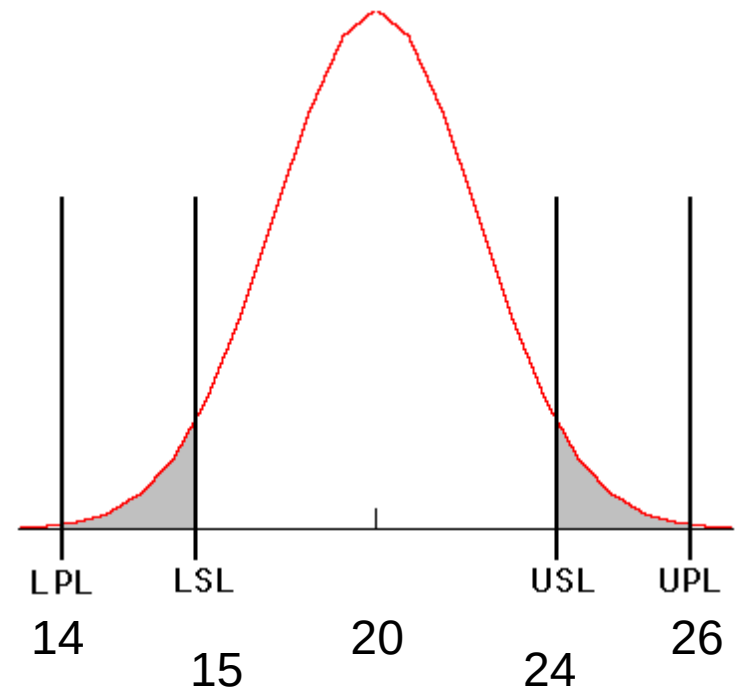
C_{pk} measures “Process Capability”

If process limits and control limits are at the same location, $C_{pk} = 1$. $C_{pk} \geq 2$ is exceptional.

Good quality: defects are rare ($C_{pk} > 1$)

Poor quality: defects are common ($C_{pk} < 1$)

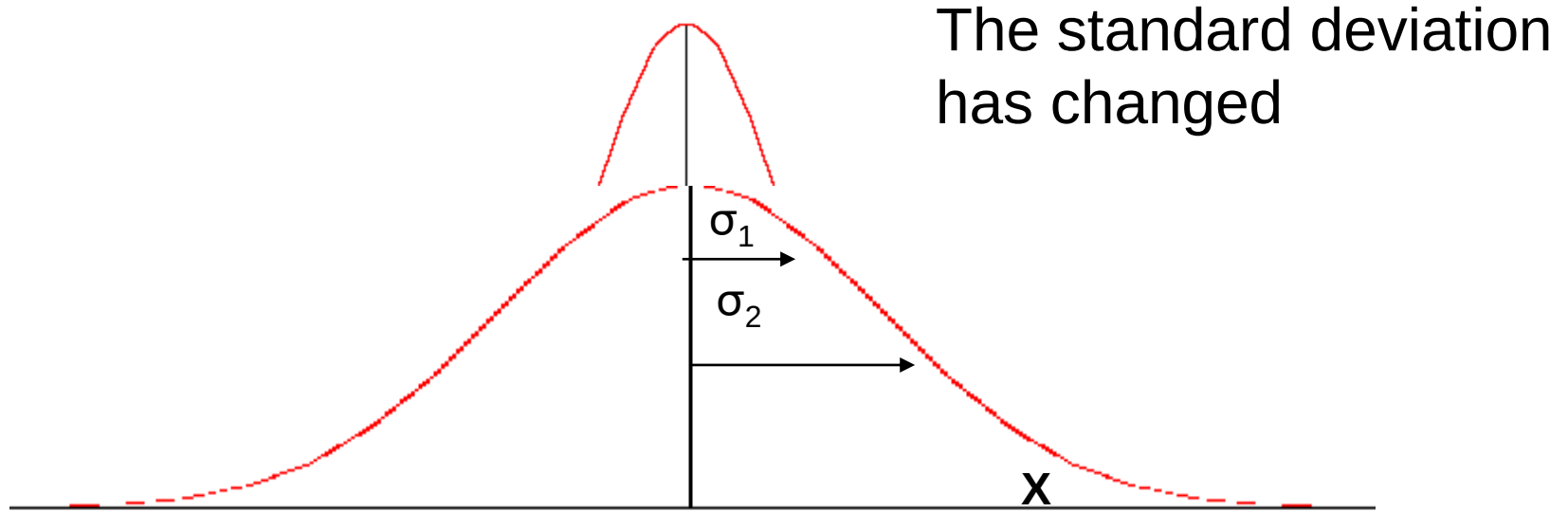
$$C_{pk} = \min \left\{ \begin{array}{l} \frac{USL - \bar{\bar{x}}}{3\sigma} = \frac{24 - 20}{3(2)} = .667 \\ \frac{\bar{\bar{x}} - LSL}{3\sigma} = \frac{20 - 15}{3(2)} = .833 \end{array} \right.$$



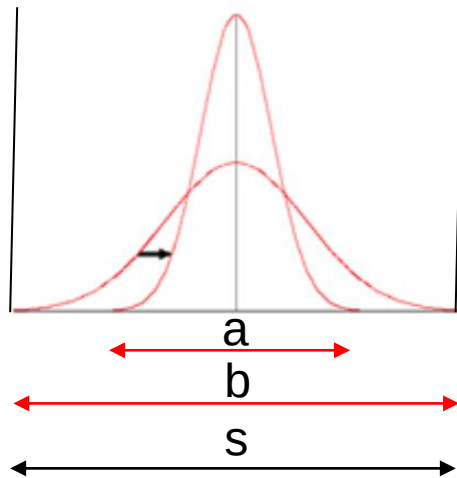
$$3\sigma = (UPL - \bar{\bar{x}}, \text{ or } \bar{\bar{x}} - LPL)$$

- When an observation is unusual, what can we conclude?

- When an observation is unusual, what can we conclude?

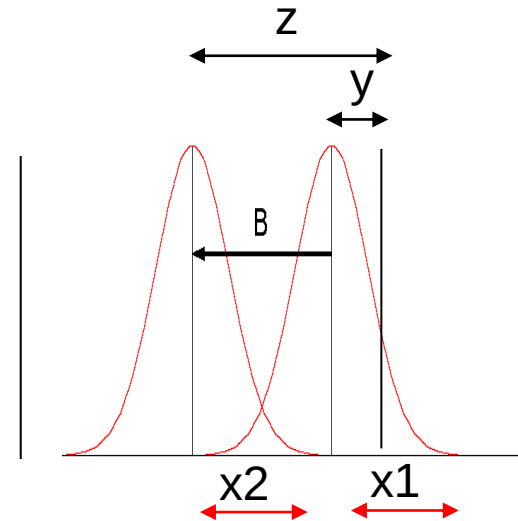


- We can now begin to recognise process drift and changes and give them values



$$\begin{aligned} s/a &= \\ Cp &2 \\ s/b &= \\ Cp &1 \end{aligned}$$

Cp measures process spread in relation to specification spread



$$\begin{aligned} y/x1 &= \\ Cpk &.5 \\ z/x2 &= \\ \text{approx} &3 \end{aligned}$$

Cpk measures process spread in relation to specification spread and its location relative to process mean and closest spec limit

Measure – Variation - Exercise

A company have a feature of a shoulder on a machined part. The specification of this shoulder is 22.00mm – 23.50mm. They want to understand their process capability. Work out control limits and Cp and Cpk. Sizes are as follows: –

22.42
22.68
22.46
22.76
22.29
22.34
22.38
22.54
22.37
22.64
22.67
22.27
22.23
22.45
22.39
22.37
22.37
22.50
22.66
22.41
22.64
22.53
22.74
22.39
22.72

Tips:-

1. Find average of the data
2. Take each individual measurements from the average
3. Square each result (to remove negatives)
4. Find average of these values (the variance)
5. Square root variance to find Std Deviation
6. Find control limits ($3 \times \text{std dev} \pm \text{ave}$)
7. Find Cp ($(\text{upper spec} - \text{lower spec}) / 6 \times \text{std dev}$)
8. Find Cpu ($(\text{upper spec limit} - \text{ave}) / 3 \times \text{std dev}$)
9. Find Cpl ($(\text{ave} - \text{lower spec limit}) / 3 \times \text{std dev}$)
10. Cpk is the lower value of 8 and 9 above
11. You can use spreadsheet sent separately

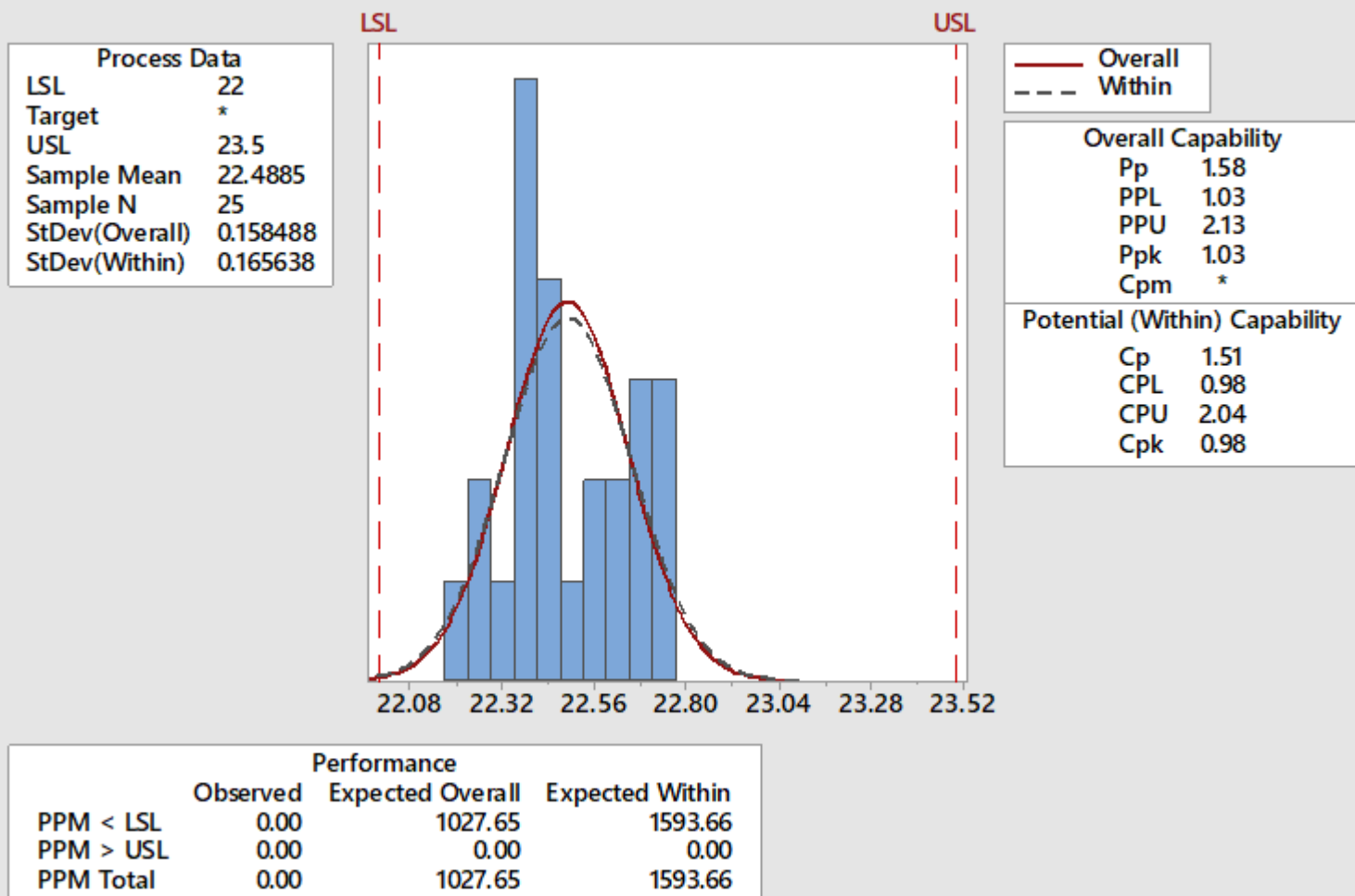
Measure – Variation - Exercise

measurements	average	diff	sq diff
22.42	22.49	-0.07	0.005
22.68	22.49	0.19	0.038
22.46	22.49	-0.03	0.001
22.76	22.49	0.27	0.074
22.29	22.49	-0.20	0.040
22.34	22.49	-0.14	0.021
22.38	22.49	-0.11	0.012
22.54	22.49	0.05	0.003
22.37	22.49	-0.12	0.013
22.64	22.49	0.15	0.022
22.67	22.49	0.18	0.034
22.27	22.49	-0.22	0.049
22.23	22.49	-0.26	0.068
22.45	22.49	-0.04	0.001
22.39	22.49	-0.10	0.009
22.37	22.49	-0.12	0.015
22.37	22.49	-0.12	0.014
22.50	22.49	0.01	0.000
22.66	22.49	0.17	0.029
22.41	22.49	-0.08	0.006
22.64	22.49	0.15	0.023
22.53	22.49	0.04	0.002
22.74	22.49	0.25	0.062
22.39	22.49	-0.10	0.010
22.72	22.49	0.23	0.053
22.49ave			0.025variance
			0.158std dev

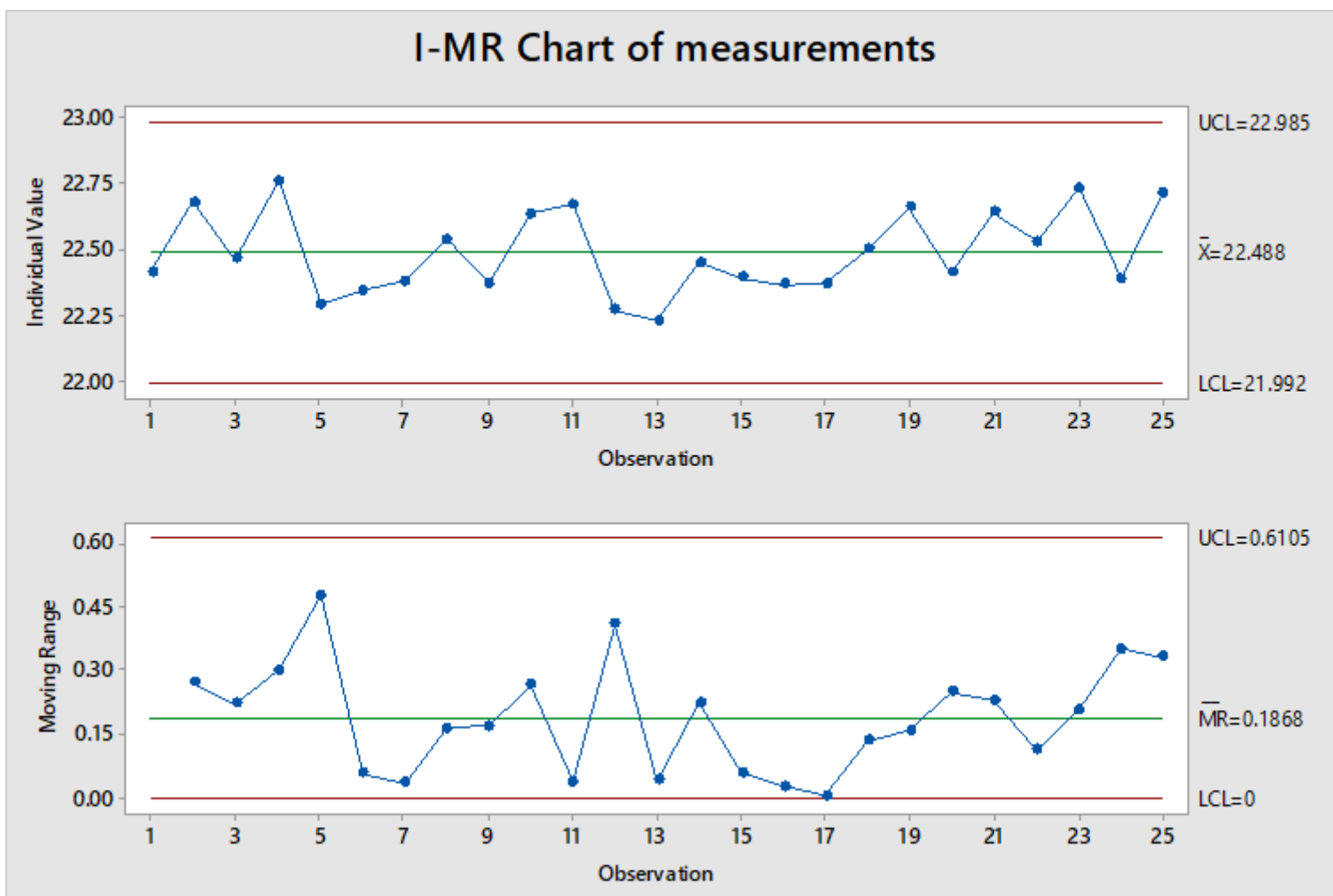
22.96UCL	lower	specification					
	22.00spec	tol		spread			
22.01LCL	23.50upper spec	1.50		0.950928		1.58Cp	
						2.13CpU	
						1.03CpL	

Measure – Variation - Exercise

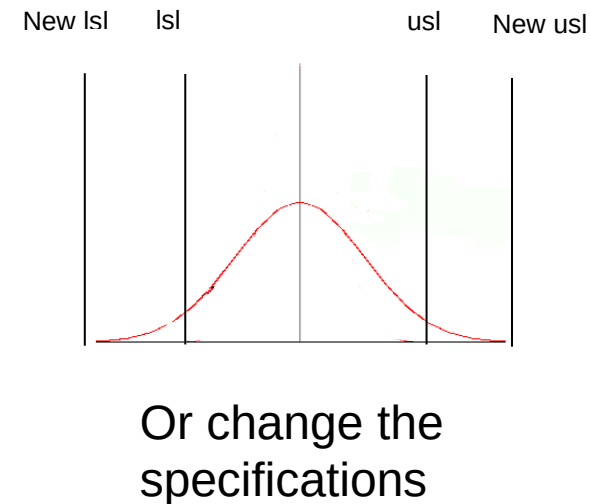
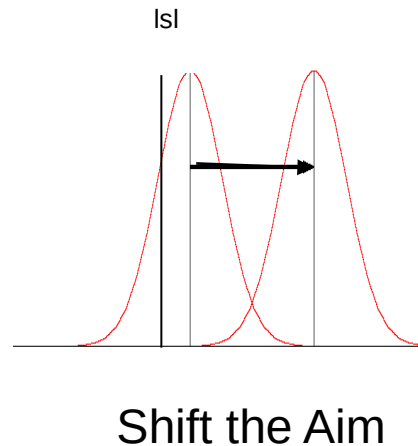
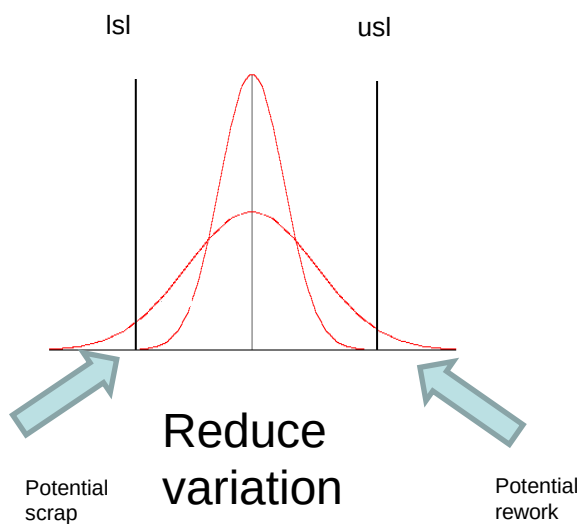
Process Capability Report for measurements



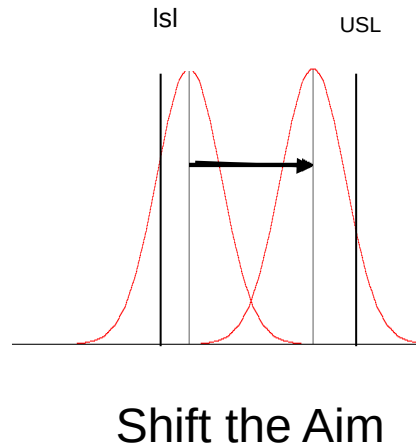
Measure – Variation - Exercise



- When we have a degree of statistical control the only way to tackle non-conforming product is to bring 'the voices' into alignment



- If you only shift the aim, the scrap reduces but you potentially have re-work to consider



Measure – Variation – Exercise 2

A company have lorries which are loaded with aggregates. The weights of the lorries should be between 20 and 23t. They want to understand their process capability. Work out control limits and Cp and Cpk. Sizes are as follows: –

20589
21256
20577
21547
21384
21400
21839
21098
20763
21441
21551
20413
20722
21247
21609
21345
21347
20424
20560
21389
20983
20652
21375
21584
21497
21188
21786
21220
21345
21581

Tips:-

1. Find average of the data
2. Take each individual measurements from the average
3. Square each result (to remove negatives)
4. Find average of these values (the variance)
5. Square root variance to find Std Deviation
6. Find control limits ($3 \times \text{std dev} \pm \text{ave}$)
7. Find Cp ($(\text{upper spec} - \text{lower spec}) / 6 \times \text{std dev}$)
8. Find Cpu ($(\text{upper spec limit} - \text{ave}) / 3 \times \text{std dev}$)
9. Find Cpl ($(\text{ave} - \text{lower spec limit}) / 3 \times \text{std dev}$)
10. Cpk is the lower value of 8 and 9 above
11. You can use spreadsheet sent separately

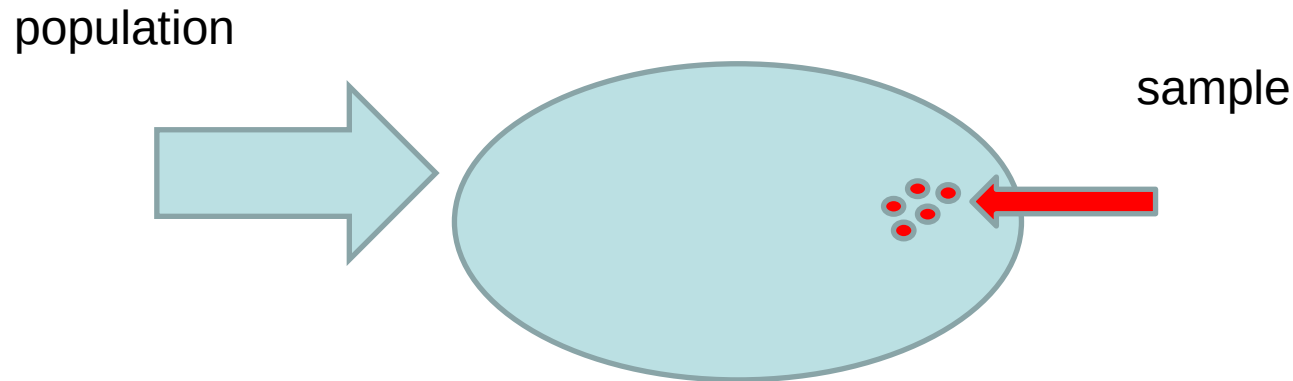
Measure – Variation - Exercise



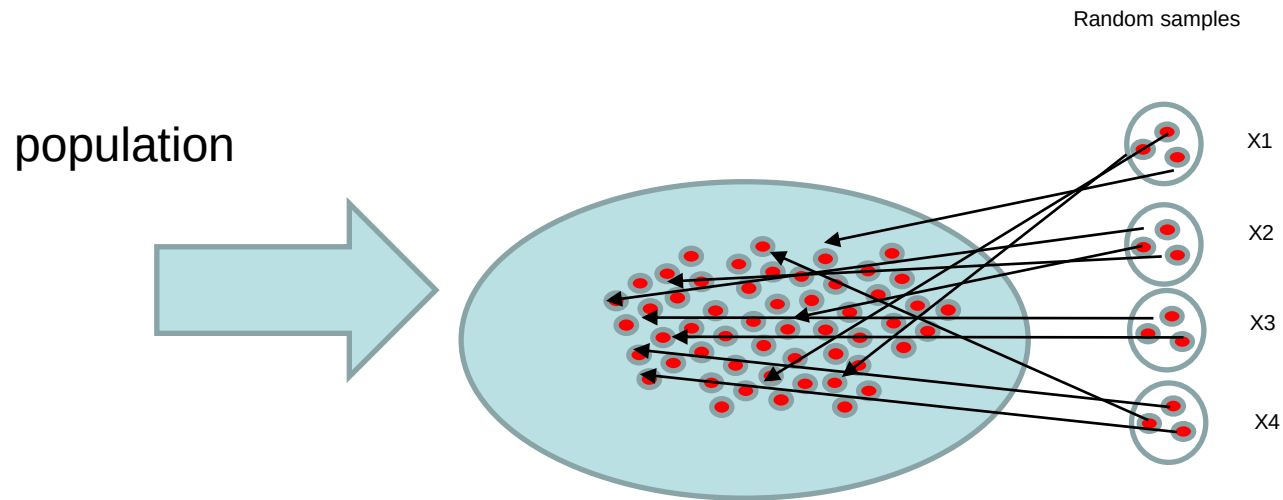
measurements	average	diff	sq diff
20589	21190.4	-601.4	361682
21256	21190.4	65.6	4303.36
20577	21190.4	-613.4	376259.6
21547	21190.4	356.6	127163.6
21384	21190.4	193.6	37480.96
21400	21190.4	209.6	43932.16
21839	21190.4	648.6	420682
21098	21190.4	-92.4	8537.76
20763	21190.4	-427.4	182670.8
21441	21190.4	250.6	62800.36
21551	21190.4	360.6	130032.4
20413	21190.4	-777.4	604350.8
20722	21190.4	-468.4	219398.6
21247	21190.4	56.6	3203.56
21609	21190.4	418.6	175226
21345	21190.4	154.6	23901.16
21347	21190.4	156.6	24523.56
20424	21190.4	-766.4	587369
20560	21190.4	-630.4	397404.2
21389	21190.4	198.6	39441.96
20983	21190.4	-207.4	43014.76
20652	21190.4	-538.4	289874.6
21375	21190.4	184.6	34077.16
21584	21190.4	393.6	154921
21497	21190.4	306.6	94003.56
21188	21190.4	-2.4	5.76
21786	21190.4	595.6	354739.4
21220	21190.4	29.6	876.16
21345	21190.4	154.6	23901.16
21581	21190.4	390.6	152568.4
21190.4ave			171667.1variance
			414.3273std dev

lower	specificati			
20000spec	on tol	spread		
	300			
23000 upper spec	0.00	2485.964		
				1.21 Cp
				1.46 CpU
				0.96 CpL

What is a sample?

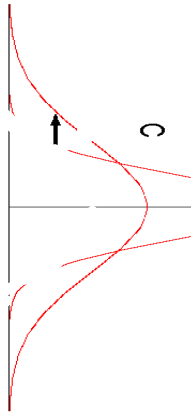


- A sample is a sub-set of all possible values
- As the sample does not contain all possible values there is some uncertainty about the population
- Any statistics are just estimates of the true population parameters

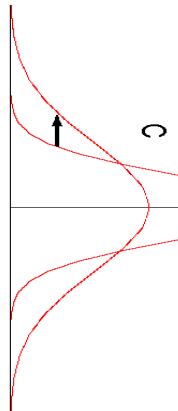


$$\text{Mean of all samples} = \frac{x_1 + x_2 + x_3 + x_4}{4}$$

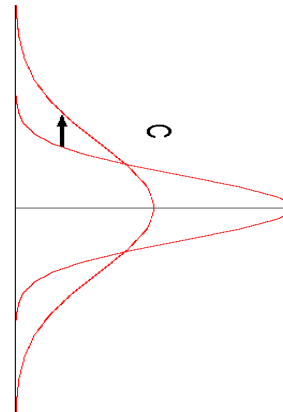
Sample 1 –
short term



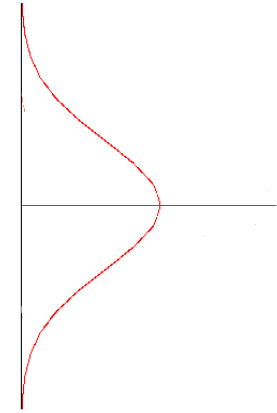
Sample 2 –
short term



Sample 3 –



Population
– long term



- Short term variation expressed as C_p and C_{pk} (within sub-groups)
- Long term variation expressed as P_p and P_{pk} (overall)
- Be warned many companies calculate long term capability and express as C_p and C_{pk}

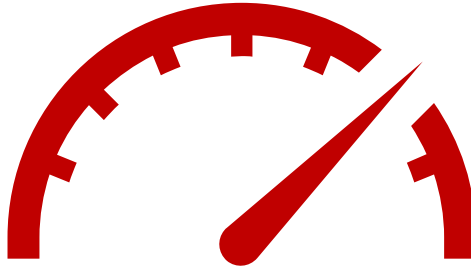


Level 5 – Continuous Improvement with Industry 4.0

Measure 3 – Overall Equipment Effectiveness (OEE)



Availability



Performance



Quality

**= Overall Equipment
Effectiveness (OEE)**



Overall Equipment Effectiveness (OEE)

Focuses on the 'six big losses' experienced within manufacturing environments:-

Availability

- Equipment failure
- Set up and changeovers

Performance

- Machinery idling
- Reduced speed

Quality

- Yield, re-work and scrap
- Start up losses



Availability - Equipment failure

- Sporadic breakdowns – these are generally obvious and easily repaired
- Chronic breakdowns – these are accepted by the organization as repeated repairs fail and are ‘part of the job’



Availability – Set-up and changeovers

- Losses occur due to excessive set-up times
- Changeovers are not repeatable and unforeseen occurrences happen



Performance – Machinery idling

- Idling between products and temporary malfunctions
- Exactly the same effect as a breakdown stopping a machine to work but can be more frequent and is often overlooked



Performance – Reduced speed

- Difference between designed speed and actual speed achieved
- Can happen when quality issues occur, or machinery develops faults



Quality – Yield, re-work and scrap

- Component does not achieve specification (VoC) so has to travel around the process again
- Component does not achieve specification, cannot be re-worked and is scrapped – control charts could help in identifying potential issues before they happen!



Overall Equipment Effectiveness (OEE)

Quality – Start up losses

- Losses occur during start up or until the process becomes stable



Availability

- Availability considers all events that stop planned production long enough where it makes sense to track a reason for being down (typically several minutes.)



$$\text{Availability} = \text{Run Time} / \text{Planned Production Time}$$

- Run time is Planned Production Time less Stop Time, where Stop Time is defined as all the time where the manufacturing process was intended to be running but was not due to unplanned stops (breakdowns) or planned stops (changeovers.)



$$\text{Run Time} = \text{Planned Production Time} - \text{Stop Time (Planned \& Unplanned)}$$

- Performance takes into account anything that causes the manufacturing process to run at less than the maximum possible speed when it is running (including both slow cycles and small stops)
- Performance is the ratio of **Net Run Time** and **Run Time**, and is calculated;

 **Performance = (Ideal Cycle Time * Total Count) / Run Time**

- **Ideal Cycle Time** is the fastest cycle time that your process can achieve in optimal circumstances. Therefore, when it is multiplied by the **Total Count** the result is **Net Run Time** (the fastest possible time to manufacturing the parts.)

 **Performance = (Total Count / Run Time) / Ideal Run Rate**

 *Performance should never be greater than 100%. If it is, that usually indicates that the Ideal Cycle Time is set incorrectly (if is too high.)*



Quality

- Quality considers manufactured parts that do not meet quality standards, including parts that need rework.

 Remember; OEE Quality is like **First Past Yield** (or **First Time Through** - FTT) in that it defines **Good Parts** as parts that successfully pass through the manufacturing process first time without needing any rework.

 **Quality = Good Count / Total Count**

- OEE considers all losses, resulting in a measure of truly productive manufacturing time.

 OEE scores provide a very valuable oversight – an accurate picture on how effectively your manufacturing process is running.

 Easy to track improvements over time.

 **OEE = Availability * Performance * Quality**

 What your OEE score doesn't provide is any insights as to the underlying causes of lost productivity. That is visible through the individual elements; **Availability, Performance and Quality.**

 In the preferred calculation you get the best of both worlds. A single number that captures how well you are doing (**OEE**) and three numbers that capture the fundamental nature of your losses (**Availability, Performance, and Quality**).

Listen to your process

- What are your thoughts on some data you've just seen from your production area for last week?

OEE Factor	16-Nov-20	23-Nov-20
OEE	85.10%	85.70%
Availability	90.00%	95.00%
Performance	95.00%	95.00%
Quality	99.50%	95.00%



OEE Calculation

Item	Data
Shift Length	8 hours (480 minutes)
Breaks	(2) 15 minute and (1) 30 minute
Downtime	47 minutes
Ideal Cycle Time	1.0 seconds
Total Count	19,271 widgets
Reject Count	423 widgets

Planned Production Time = Shift Length – Breaks

Run Time = Planned Production Time - Stop Time

Good Count = Total Count – Reject Count

Availability = Run Time / Planned Production Time

Performance = (Total Count / Run Time) / Ideal Run Rate

Quality = Good Count / Total Count

OEE = Availability * Performance * Quality



OEE Calculation

Item	Data
Shift Length	8 hours (480 minutes)
Breaks	(2) 15 minute and (1) 30 minute
Downtime	47 minutes
Ideal Cycle Time	1.0 seconds
Total Count	19,271 widgets
Reject Count	423 widgets

Planned Production Time = Shift Length – Breaks = 480mins - 60mins = **420mins**

Run Time = Planned Production Time - Stop Time = 420mins – 47mins = **373mins**

Good Count = Total Count – Reject Count = 19,271 – 423 = **18,848**

Availability = Run Time / Planned Production Time = 373mins / 420mins = **0.8881** (88.81%)

Performance = (Total Count / Run Time x id. cycle time) = (19,271 / 373mins x 60) = **0.8611** (86.11%)

Quality = Good Count / Total Count = 18,848 / 19,271 = **0.9780** (97.80%)

OEE = Availability * Performance * Quality = 0.881 * 0.8611 * 0.9780 = **0.7479 (74.79%)**



OEE Calculation - Exercise

Inputs		
Shift Length	720	minutes
Breaks	45	minutes
Downtime	67	minutes
Ideal Cycle Time	1	minutes
Total Count	567	Parts
Reject Count	23	Parts



OEE Calculation

Inputs		
Shift Length	720	minutes
Breaks	45	minutes
Downtime	67	minutes
Ideal Cycle Time	1	minutes
Total Count	567	Parts
Reject Count	23	Parts

Planned Production Time = Shift Length – Breaks = $720mins - 45mins = 675mins$

Run Time = Planned Production Time - Stop Time = $675mins - 67mins = 608mins$

Good Count = Total Count – Reject Count = $567 - 23 = 544$

Availability = Run Time / Planned Production Time = $608mins / 675mins = 0.9007(90\%)$

Performance = (parts made / Run Time x id.cycle time) = $(567 / 608mins \times 1) = 0.932 (93.2\%)$

Quality = Good Count / Total Count = $544 / 567 = 0.959 (95.9\%)$

OEE = Availability * Performance * Quality = $0.9007 * 0.932 * 0.959 = 0.805 (80.5\%)$



OEE Calculation - Exercise

		06-Jan-20		13-Jan-20		20-Jan-20	
Inputs		AM Shift	PM Shift	AM Shift	PM Shift	AM Shift	PM Shift
Shift Length	720 minutes	720	720	720	720	720	720
Breaks	45 minutes	60	60	60	60	60	60
Downtime	67 minutes	43	47	45	320	65	45
Ideal Cycle Time	1 minutes	1	1	1	1	1	1
Total Count	567 Parts	498	435	587	238	576	568
Reject Count	23 Parts	13	17	23	45	23	18
Calculations							
Planned Production Time	675 minutes	675	675	675	675	675	675
Run Time	608 minutes	632	628	630	355	610	630
Good Count	544 Parts	485	418	564	193	553	550
Availability	90.07%	93.63%	93.04%	93.33%	52.59%	90.37%	93.33%
Performance	93.26%	78.80%	69.27%	93.17%	67.04%	94.43%	90.16%
Quality	95.94%	97.39%	96.09%	96.08%	81.09%	96.01%	96.83%
OEE	80.59%	71.85%	61.93%	83.56%	28.59%	81.93%	81.48%

