University of Glasgow

电子科技大学
University of Electronic Science and Technology of China

UESTC 3031: Engineering Project Management & Finance: Design for Manufacturing

Lecture DFM 2: Process Capability

Dr Duncan Bremner

Design for Manufacturing
Process Capability

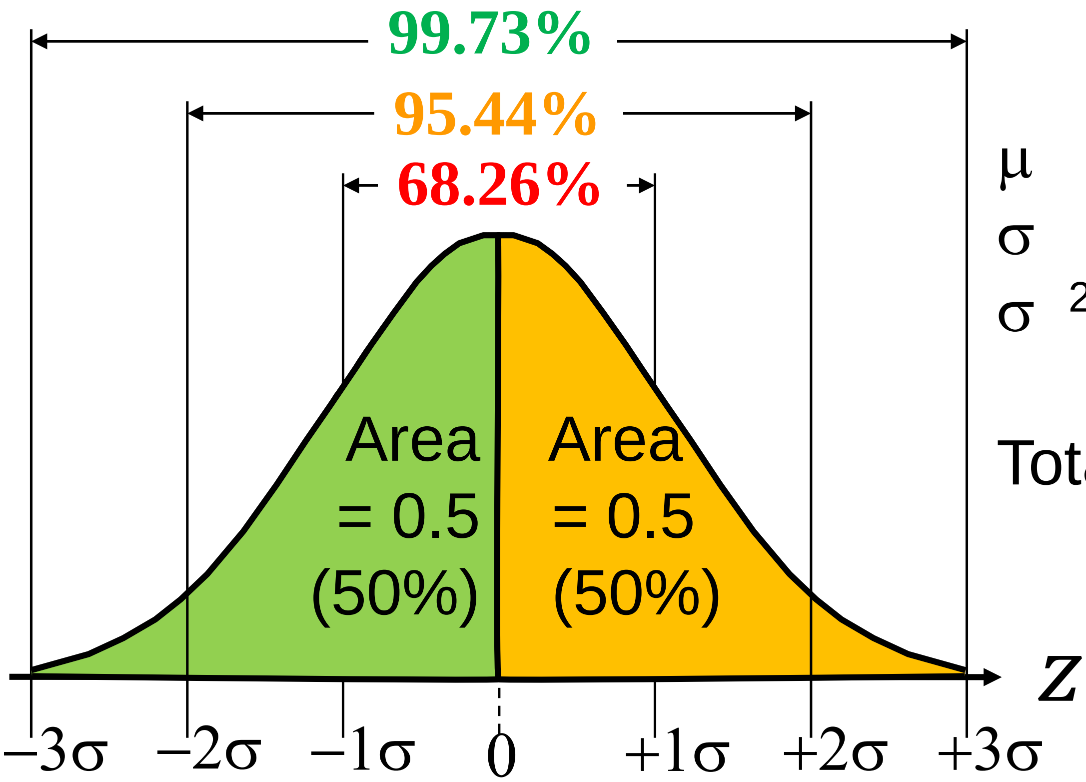
Last Lecture: Summarised the importance of Design for Manufacturing-> 75% of product cost can be influenced by design

This lecture will include

1. Quick revision of Normal distribution
2. Introduction to process and component variability
3. How to measure process variability
4. Process and product quality control & SPC

Thank you to Dr John Shackleton for his help in preparing this lecture

Quick Review of Normal distributions



μ = mean

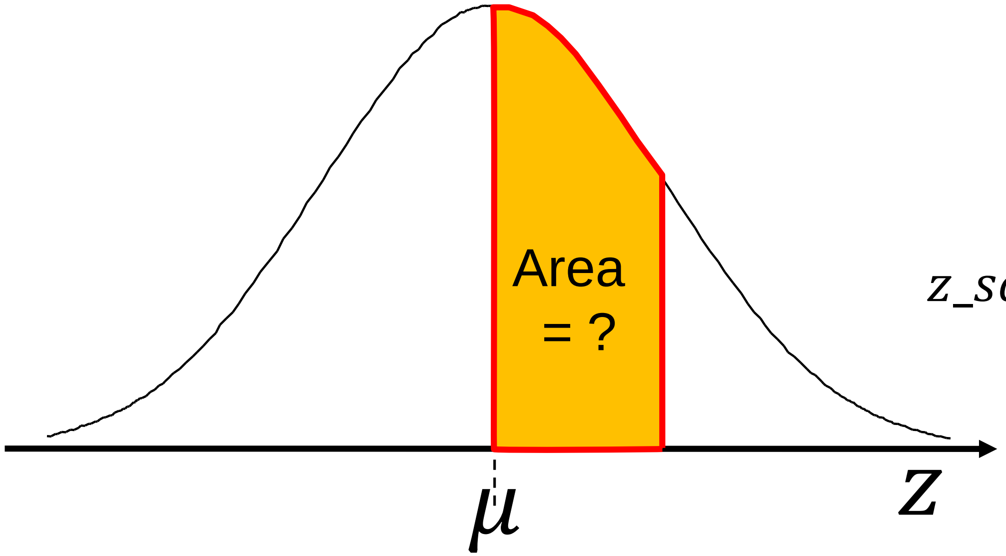
σ = standard deviation

σ^2 = variance

Total Area under curve =1

$$z\_score = \frac{Value - Mean}{Standard\ Deviation}$$

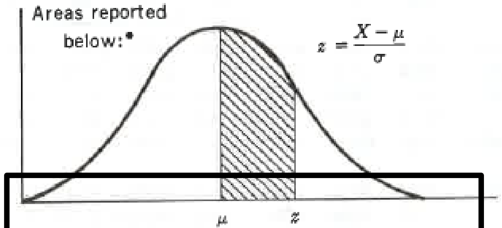
Quick Review of Normal distributions



$$z\_score = \frac{Value - Mean}{Standard\ Deviation}$$

Need to use tables to look up area under curve

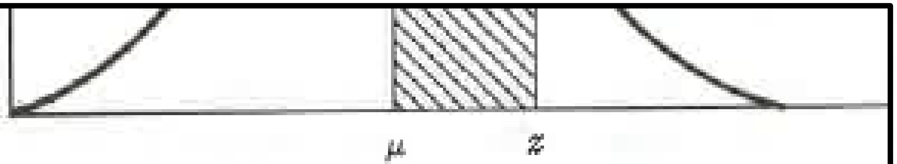
APPENDIX 2 AREAS UNDER THE STANDARD NORMAL PROBABILITY DISTRIBUTION



z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.0000	.0040	.0080	.0120	.0160	.0199	.0239	.0279	.0319	.0359
0.1	.0398	.0438	.0478	.0517	.0557	.0596	.0636	.0675	.0714	.0753
0.2	.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064	.1103	.1141
0.3	.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443	.1480	.1517
0.4	.1554	.1591	.1628	.1664	.1700	.1736	.1772	.1808	.1844	.1879
0.5	.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157	.2190	.2224
0.6	.2257	.2291	.2324	.2357	.2389	.2422	.2454	.2486	.2518	.2549
0.7	.2580	2.612	.2642	.2673	.2704	.2734	.2764	.2794	.2823	.2852
0.8	.2881	.2910	.2939	.2967	.2995	.3023	.3051	.3078	.3106	.3133
0.9	.3159	.3186	.3212	.3238	.3264	.3289	.3315	.3340	.3365	.3389
1.0	.3413	.3438	.3461	.3485	.3508	.3531	.3554	.3577	.3599	.3621
1.1	.3643	.3665	.3686	.3708	.3729	.3749	.3770	.3790	.3810	.3830
1.2	.3849	.3869	.3888	.3907	.3925	.3944	.3962	.3980	.3997	.4014
1.3	.4032	.4049	.4066	.4082	.4099	.4115	.4131	.4147	.4162	.4177
1.4	.4192	.4207	.4222	.4236	.4251	.4265	.4279	.4292	.4306	.4319
1.5	.4332	.4345	.4357	.4370	.4382	.4394	.4406	.4418	.4429	.4441
1.6	.4452	.4463	.4474	.4484	.4495	.4505	.4515	.4525	.4535	.4545
1.7	.4554	.4564	.4573	.4582	.4591	.4599	.4608	.4616	.4625	.4633
1.8	.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693	.4699	.4706
1.9	.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4756	.4761	.4767
2.0	.4772	.4778	.4783	.4788	.4793	.4798	.4803	.4808	.4812	.4817
2.1	.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850	.4854	.4857
2.2	.4861	.4864	.4868	.4871	.4875	.4878	.4881	.4884	.4887	.4890
2.3	.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911	.4913	.4916
2.4	.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932	.4934	.4936
										52
										64
										74
										81
										86
										90
4.0	.4999683									

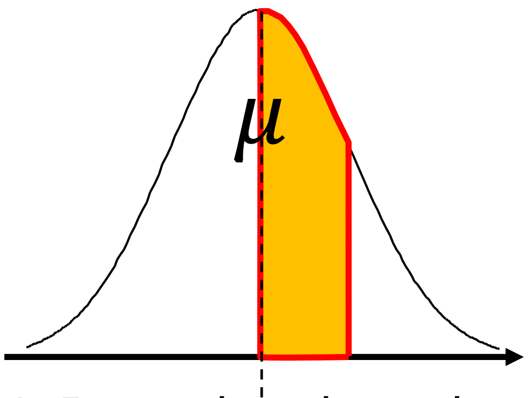
* Example: For $z = 1.96$, the shaded area is 0.4750 out of the total area of 1.0000.

0.3413 (34.13%) are above the mean(0) but less than +1 sigma

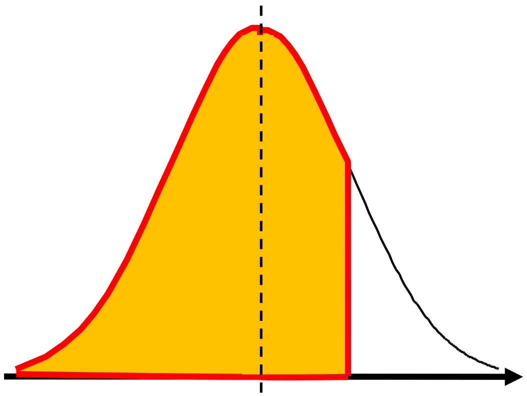


z	.00	.01	.02	.03
0.0	.0000	.0040	.0080	.0120
0.1	.0398	.0438	.0478	.0517
0.2	.0793	.0832	.0871	.0910
0.3	.1179	.1217	.1255	.1293
0.4	.1554	.1591	.1628	.1664
0.5	.1915	.1950	.1985	.2019
0.6	.2257	.2291	.2324	.2357
0.7	.2580	2.612	.2642	.2673
0.8	.2881	.2910	.2939	.2967
0.9	.3159	.3186	.3212	.3238
1.0	.3413	.3438	.3461	.3485
1.1	.3643	.3665	.3686	.3708

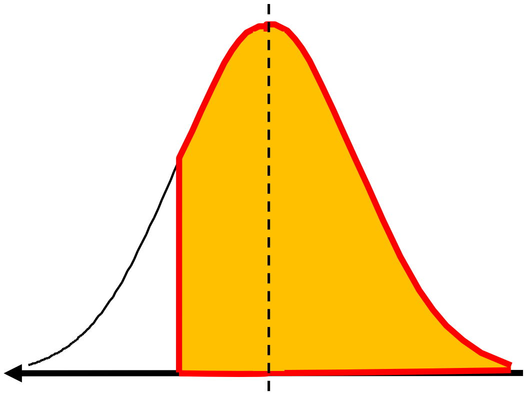
You can now calculate the 6 other options …



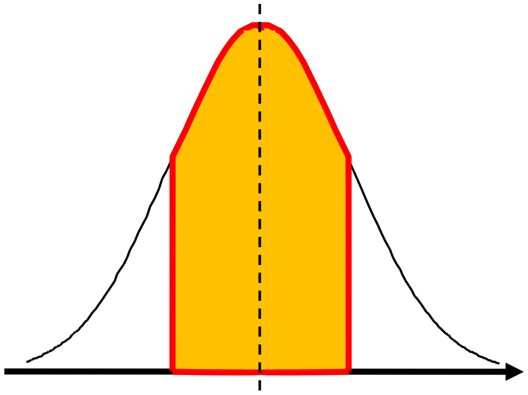
1. Proportion above the mean but less than ‘z’



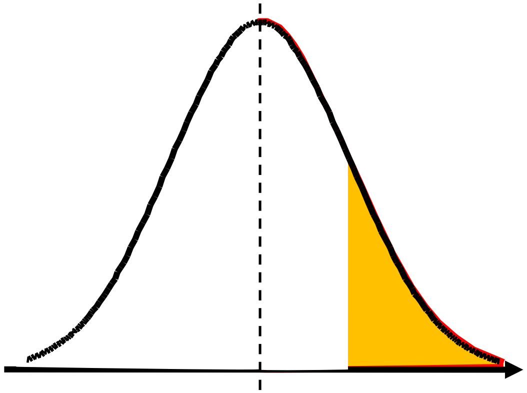
2. Proportion less than ‘z’



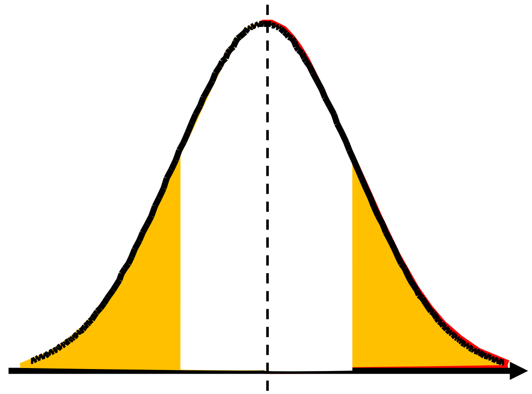
3. Proportion > -z



4. Proportion between +/- z around the mean



5. Proportion > z



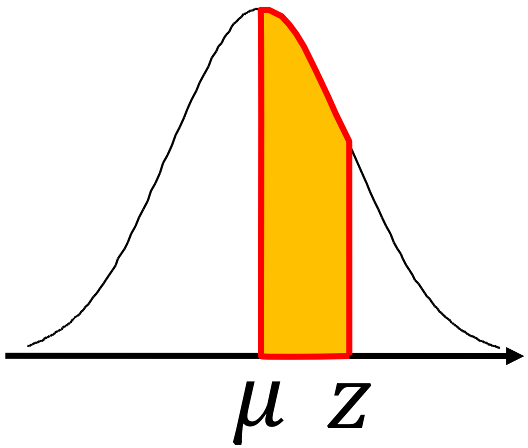
6. Proportion < -z and >z

Where to find 'Normal Distribution' tables

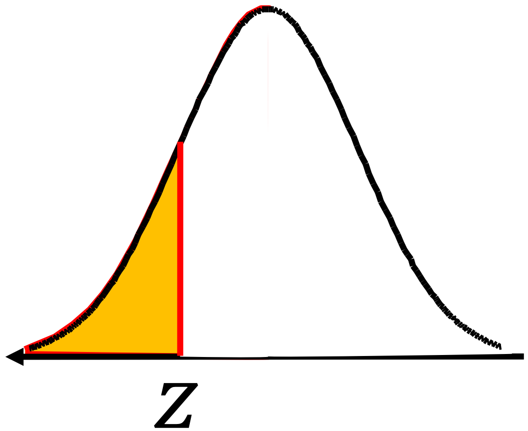
Download from the web

Often in the back of maths text books

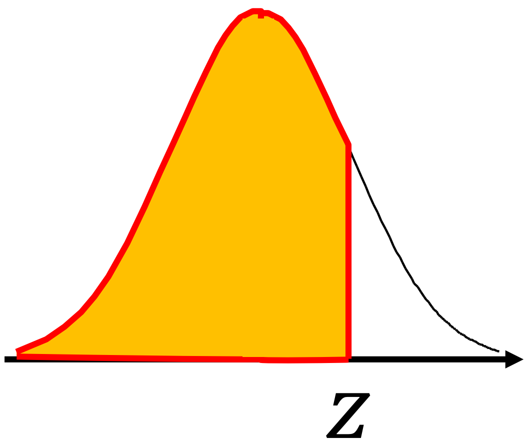
Be careful of the format they are presented:-



1. Area between the mean and 'z'



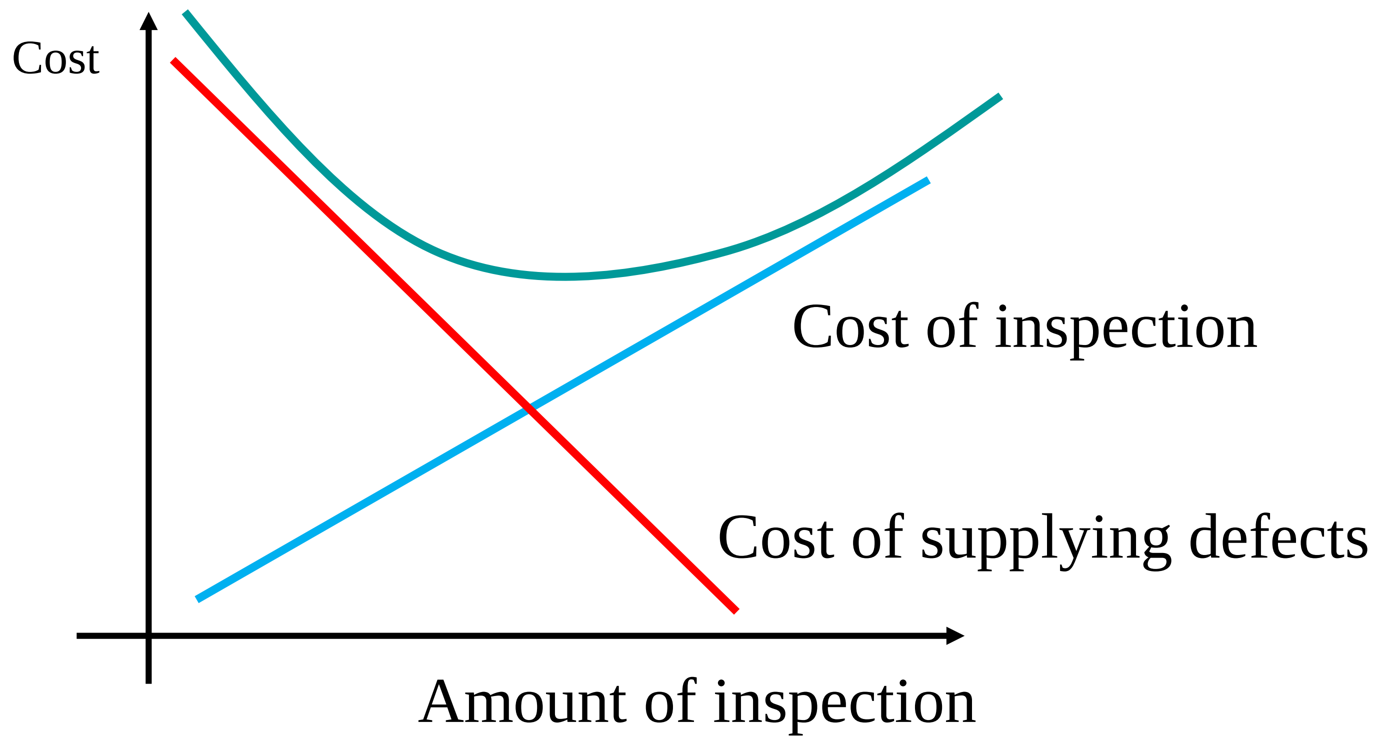
2. Area to the left of 'z' (below the mean)



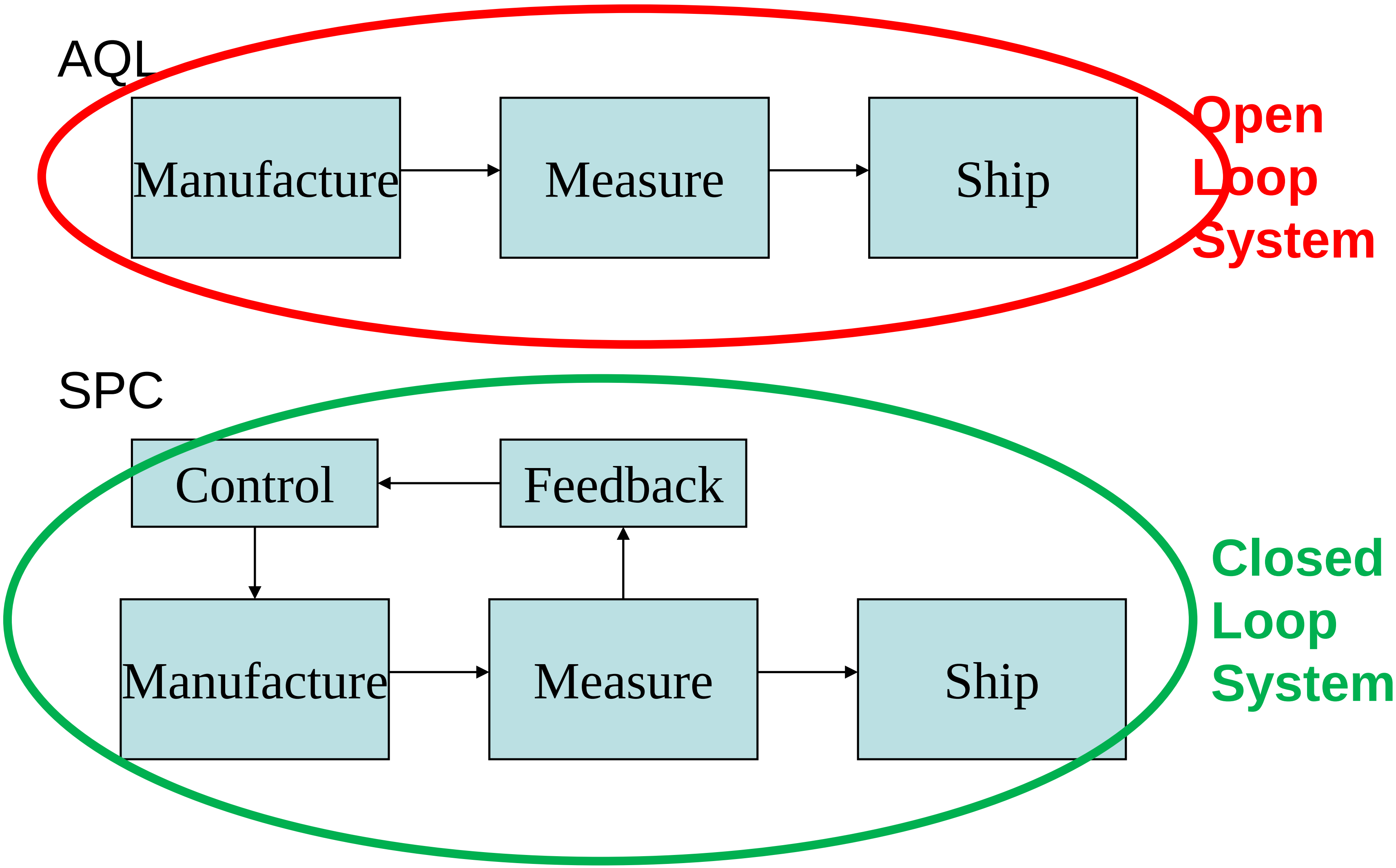
3. Area to the left of 'z' (above the mean)

Exercise: Look at the tables given to you on Moodle and recognise the difference

Acceptable Quality Level - (An <u>Outdated</u> Approach)



Acceptable Quality Level vs Statistical Process Control



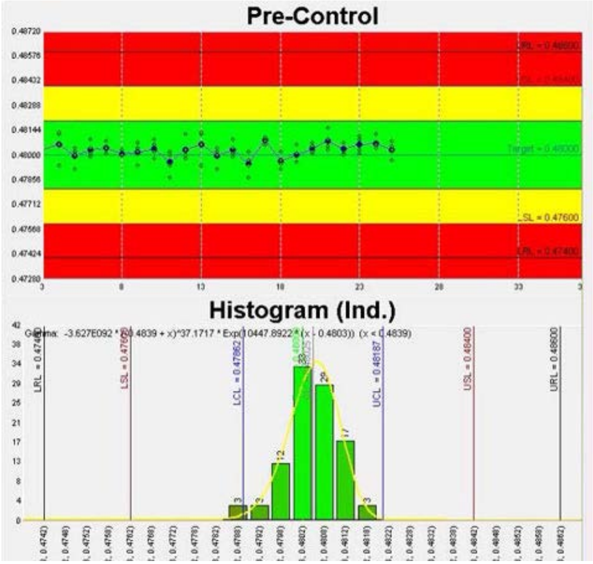
Acceptable Quality Level vs Statistical Process Control

AQL philosophy

- Minimum cost = optimise inspection
- Define limits for ‘acceptable failures’

SPC philosophy

- Minimum cost = zero defects
- Do not tolerate <u>any</u> failures
- Continual Improvement
- Feedback loops based on control charts and data



What to Measure?
(Continuous Variables)

Where is the process centre?

Measures of Location

- Mean
- Median
- Mode

How far does process vary from the centre?

Measures of Dispersion

- Range
- Variance
- Standard Deviation
  - **σ for population**
  - ***s* for sample**

Two Complementary Issues

Machine or Process Capability

The inherent variability of a particular (specific) manufacturing process.

i.e., the accuracy with which the process is capable of producing a specific parameter

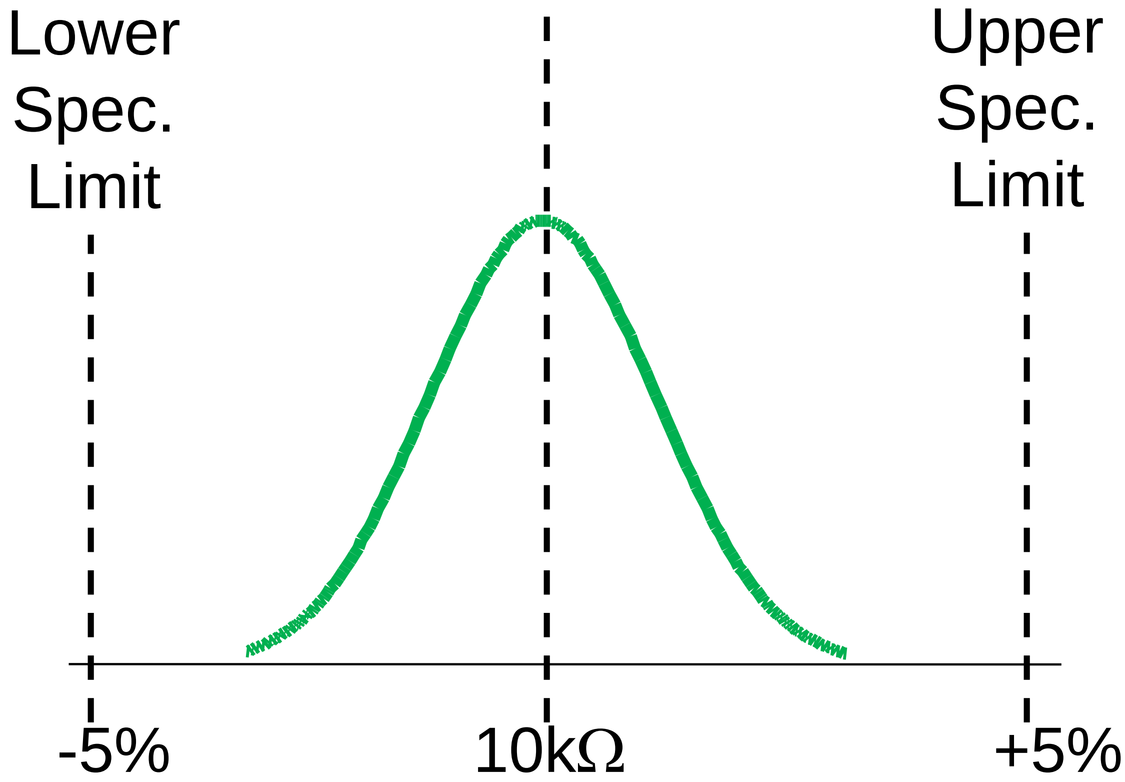
Design Tolerance

The process variation whereby the component will still function acceptably

i.e., the deviation from nominal value <u>which the design will tolerate</u>

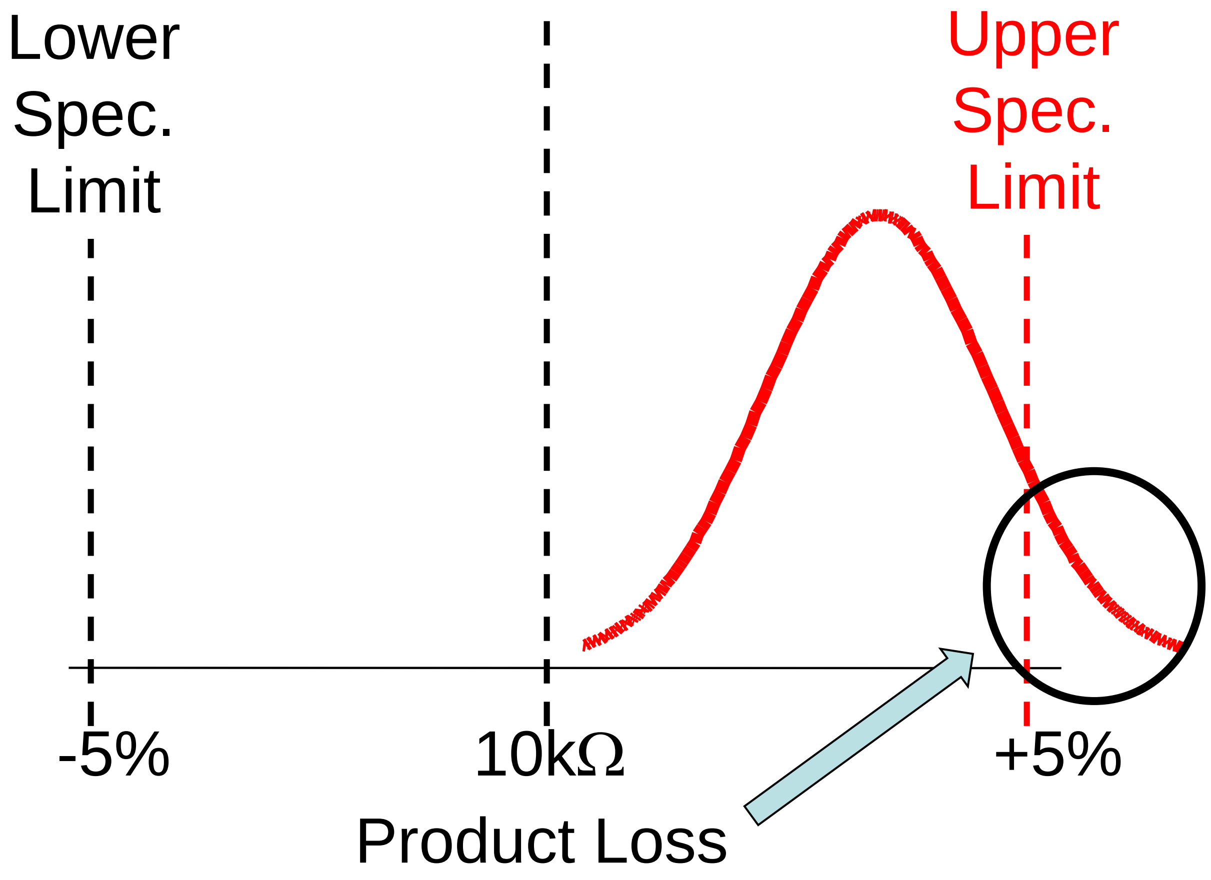
Process Capability: Component Tolerance (e.g. Resistors)

‘Capable’ and Centred

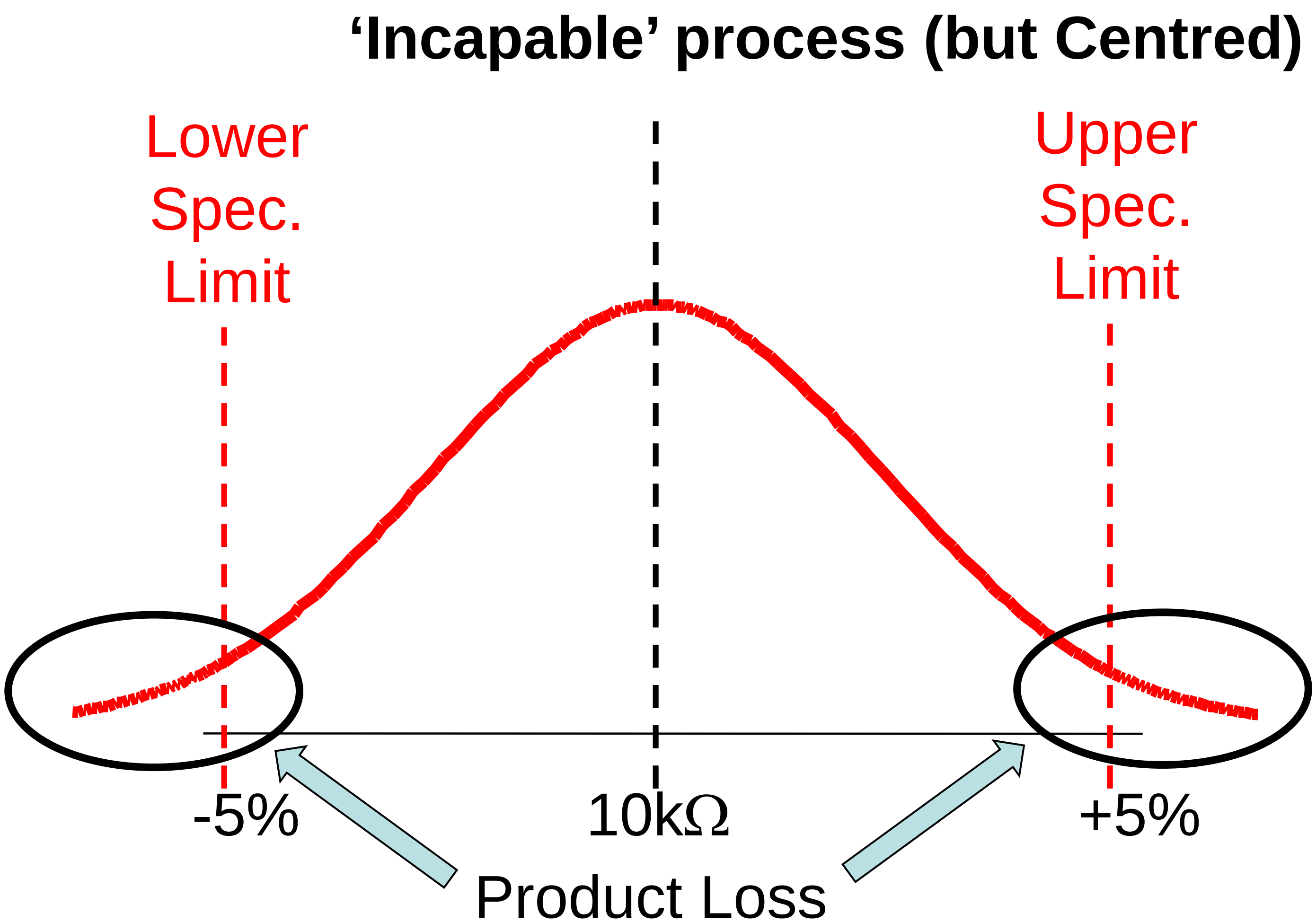


Process Capability: Component Tolerance (e.g. Resistors)

'Capable' but NOT Centred



Process Capability: Component Tolerance (e.g. Resistors)



Capability Indices +/- 3σ

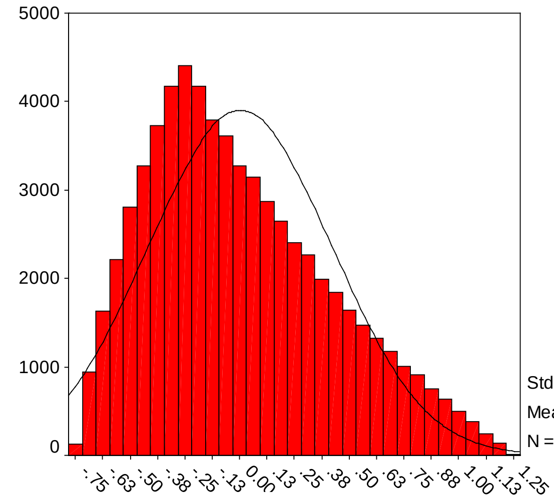
Cp – Process capability

Cpk – Process capability where adjustment of the mean is not possible (e.g. we want μ =10K Ω)

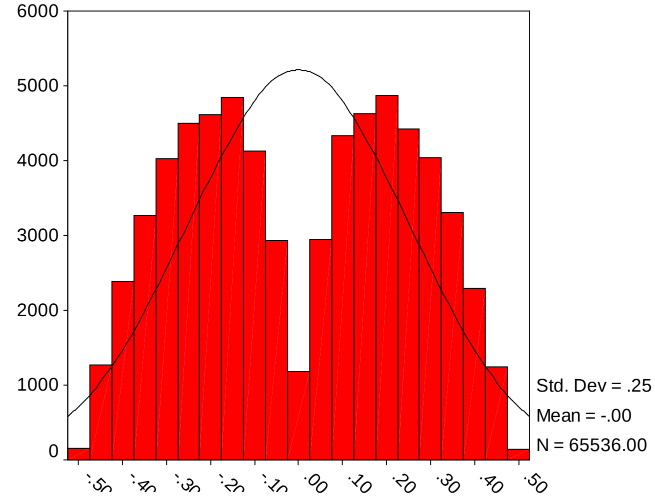
$$Cp = \frac{\text{Upper tol. limit} - \text{Lower tol. Limit}}{6 \times \text{Standard Deviation}}$$

$$Cpk = \frac{\left|\text{Nearest tol. limit} - \text{Mean}\right|}{3 \times \text{Standard Deviation}}$$

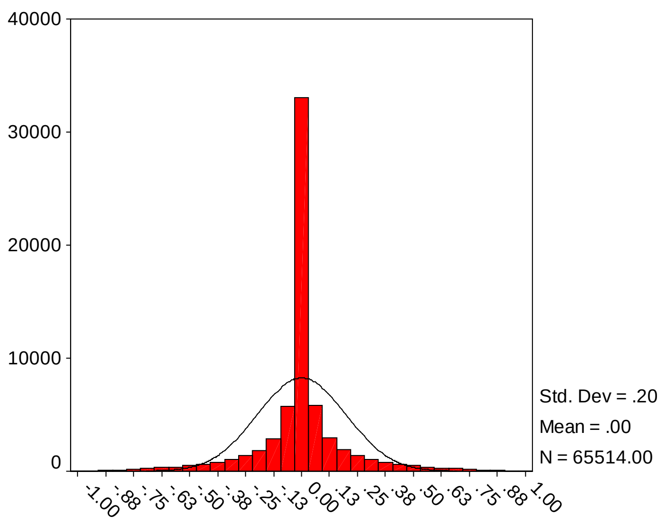
All our discussions ASSUME Normal Distribution

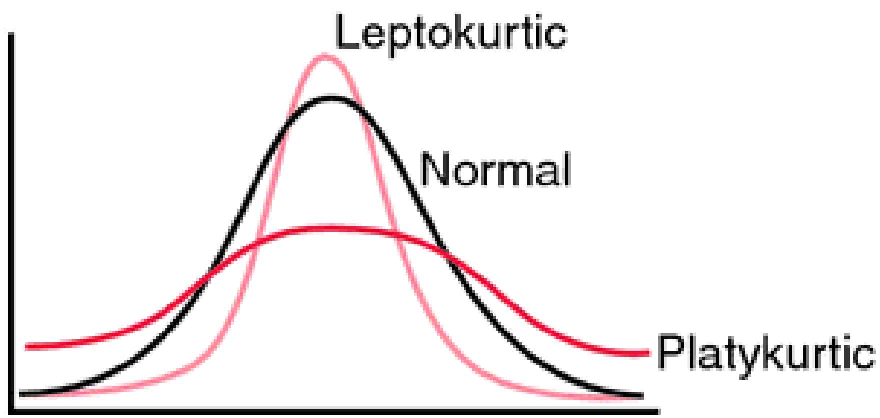


Skewed



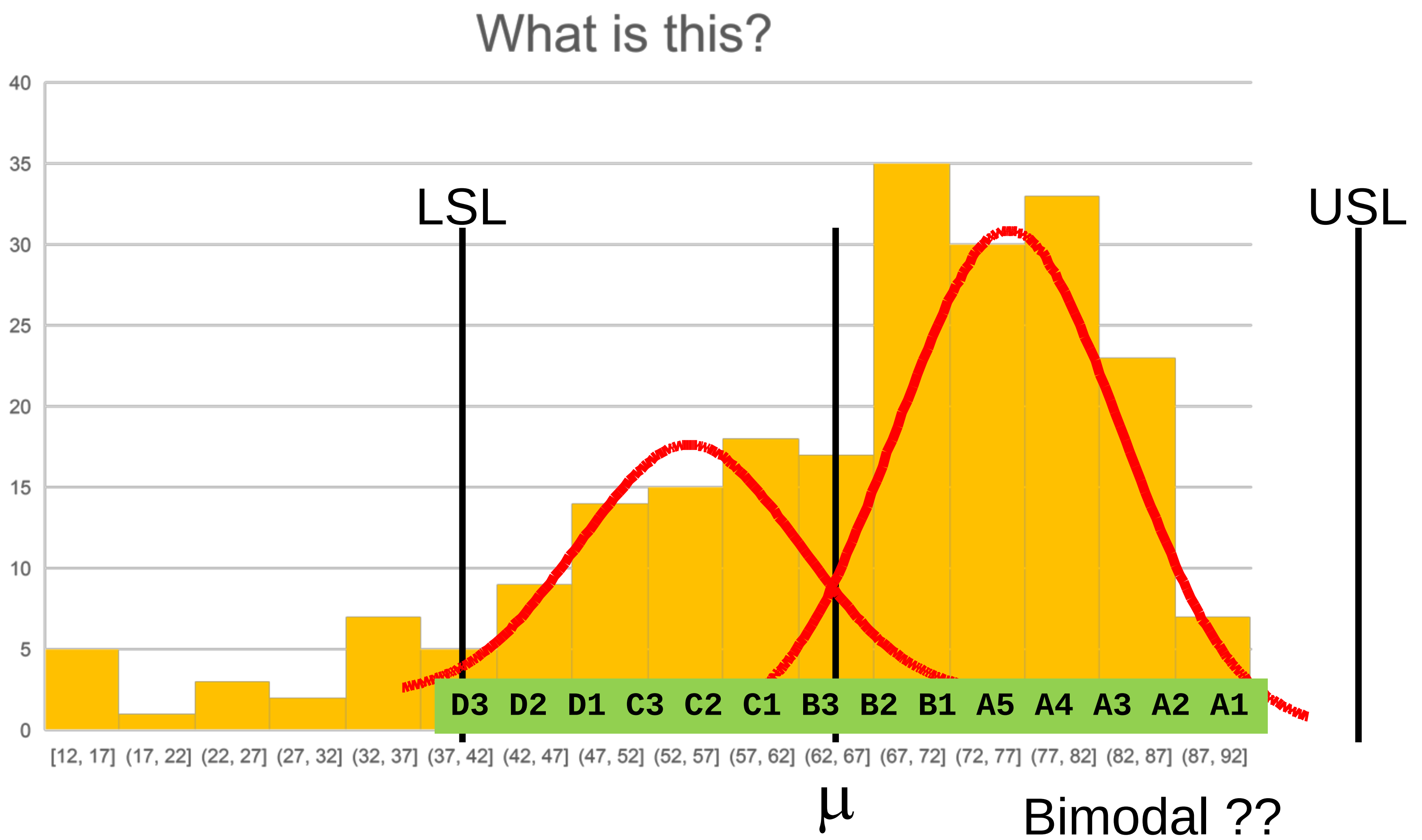
Bimodal





Leptokurtic (Kurtosis = ‘Peakiness’)

Is this distribution normal?



Process Capability Measurements

1. Is the distribution ‘normal’?

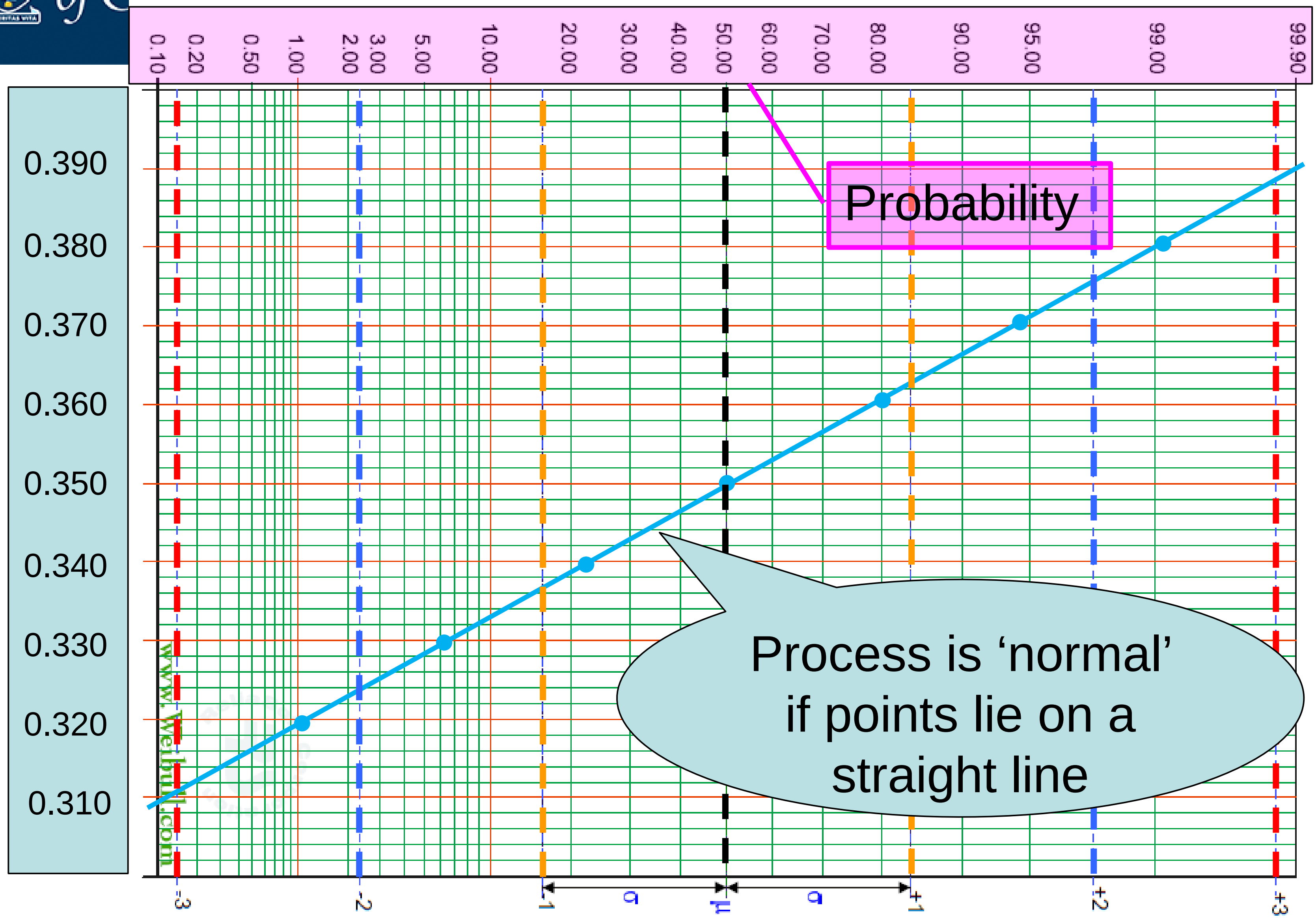
2. Is it ‘centred’?

3. What is the ‘spread’ on results (is it ‘capable’)?

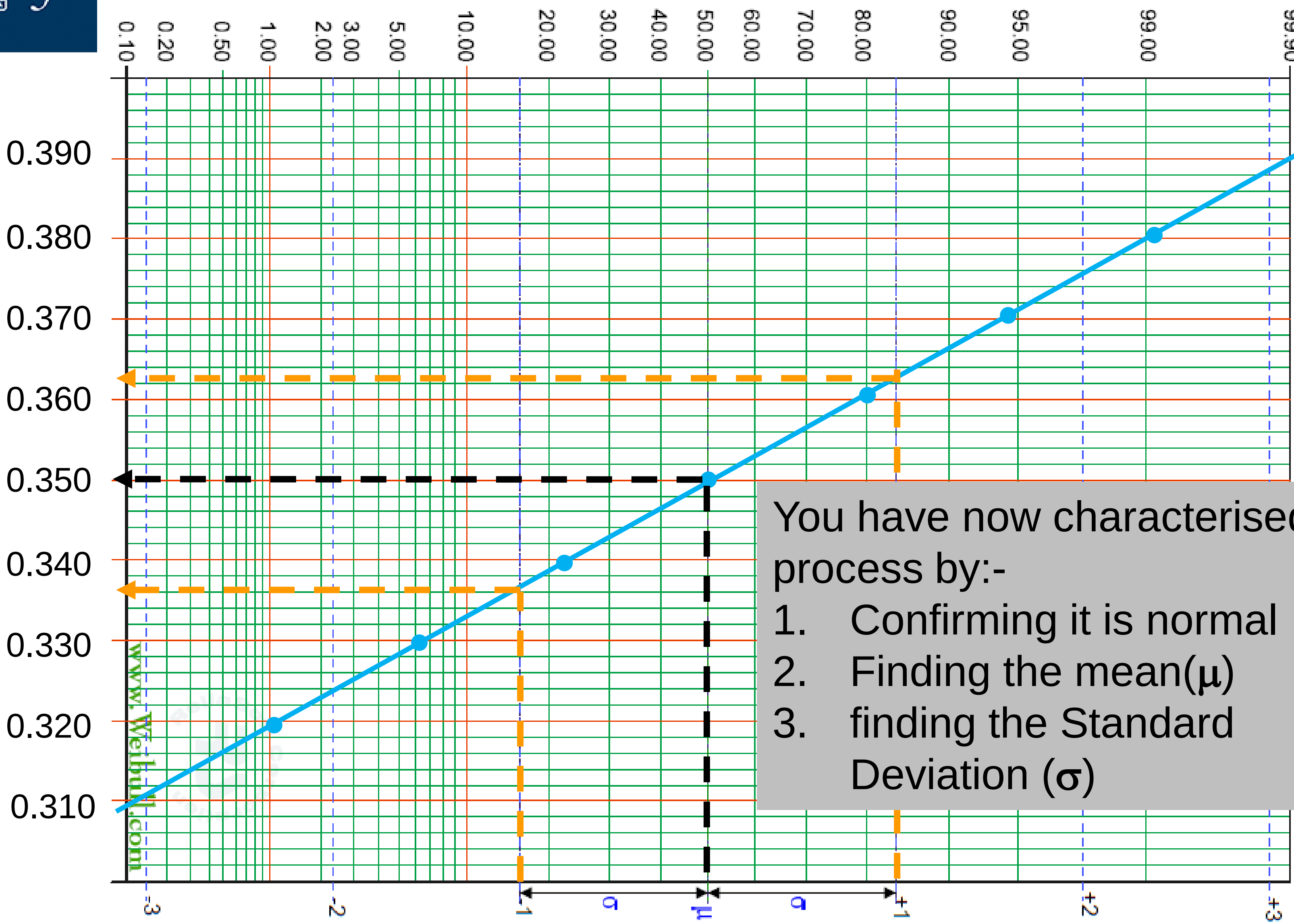
4. We have some tools to help here…

   There are automatic / algorithms but this manual method is very accurate and provides greater insight

Normal Probability Plots



Normal Probability Plots



You have now characterised the process by:-

1. Confirming it is normal
2. Finding the mean(μ)
3. finding the Standard Deviation (σ)

Ford

Capability Study

For Normal distribution

Study performed at:			
Characteristic: H9/e9 SHAFT	Dimension: 60MM NOMINAL	Operation:	Standard Deviation:
Part No:	Name:		

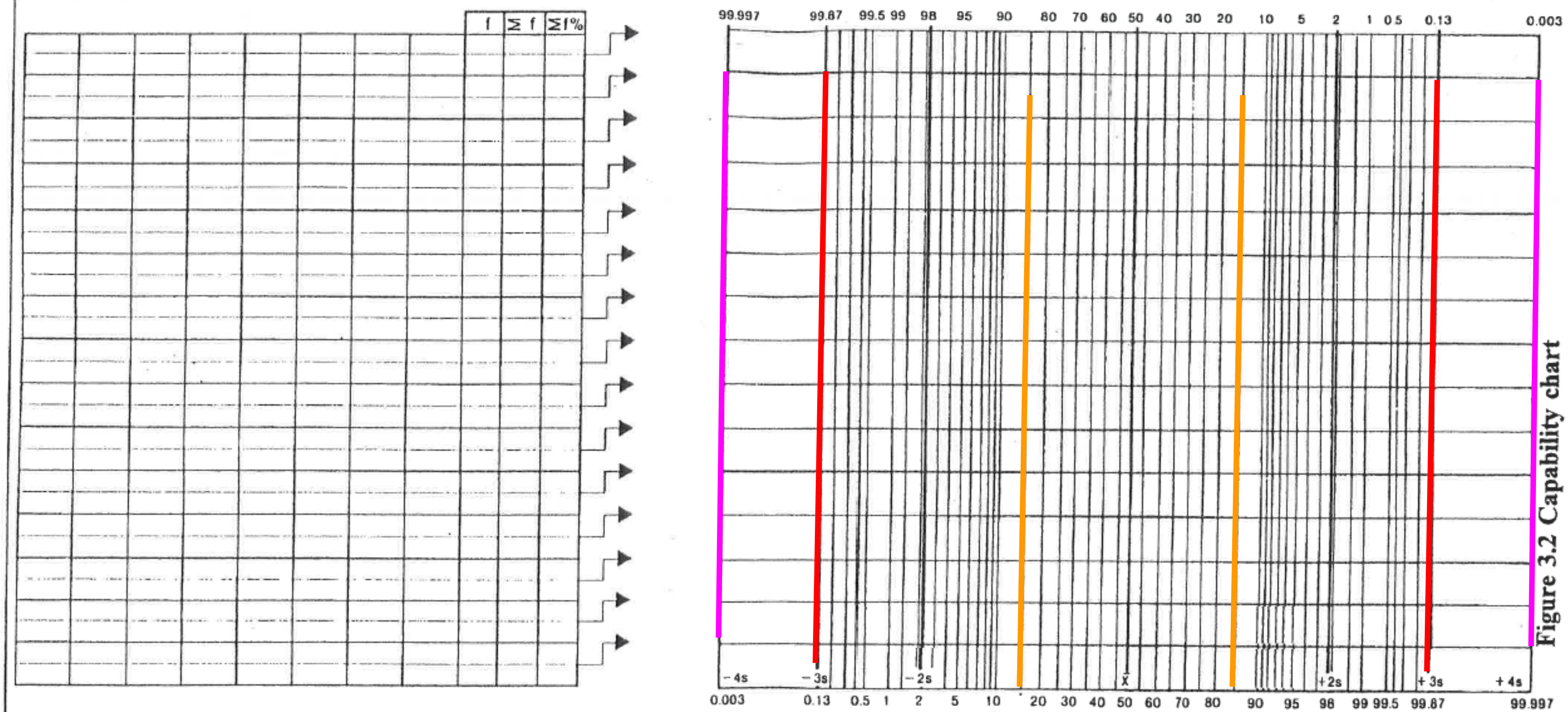


Figure 3.2 Capability chart

Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
1 59.934	6 59.929	11 59.928	16 59.905	21 59.933	26 59.910	31 59.914	36 59.914	41 59.919	46 59.923
2 59.901	7 59.925	12 59.911	17 59.906	22 59.937	27 59.912	32 59.930	37 59.908	42 59.922	47 59.912
3 59.926	8 59.921	13 59.919	18 59.921	23 59.917	28 59.923	33 59.897	38 59.926	43 59.919	48 59.902
4 59.912	9 59.913	14 59.922	19 59.945	24 59.917	29 59.906	34 59.915	39 59.923	44 59.932	49 59.936
5 59.915	10 59.918	15 59.939	20 59.924	25 59.936	30 59.926	35 59.914	40 59.912	45 59.928	50 59.925

Qual. Con. FU1C12a

Estimated out of tolerance	Specified tolerance	Target value
	Estimated capability (8s)	Estimated mean
Top % Bottom %	Capability index	
Study performed by:		
Name	Signature	Date

University of Glasgow

How to complete a Capability Chart

1. Complete the general information FIRST!!

Data collected without **when /where /why** is USELESS!!

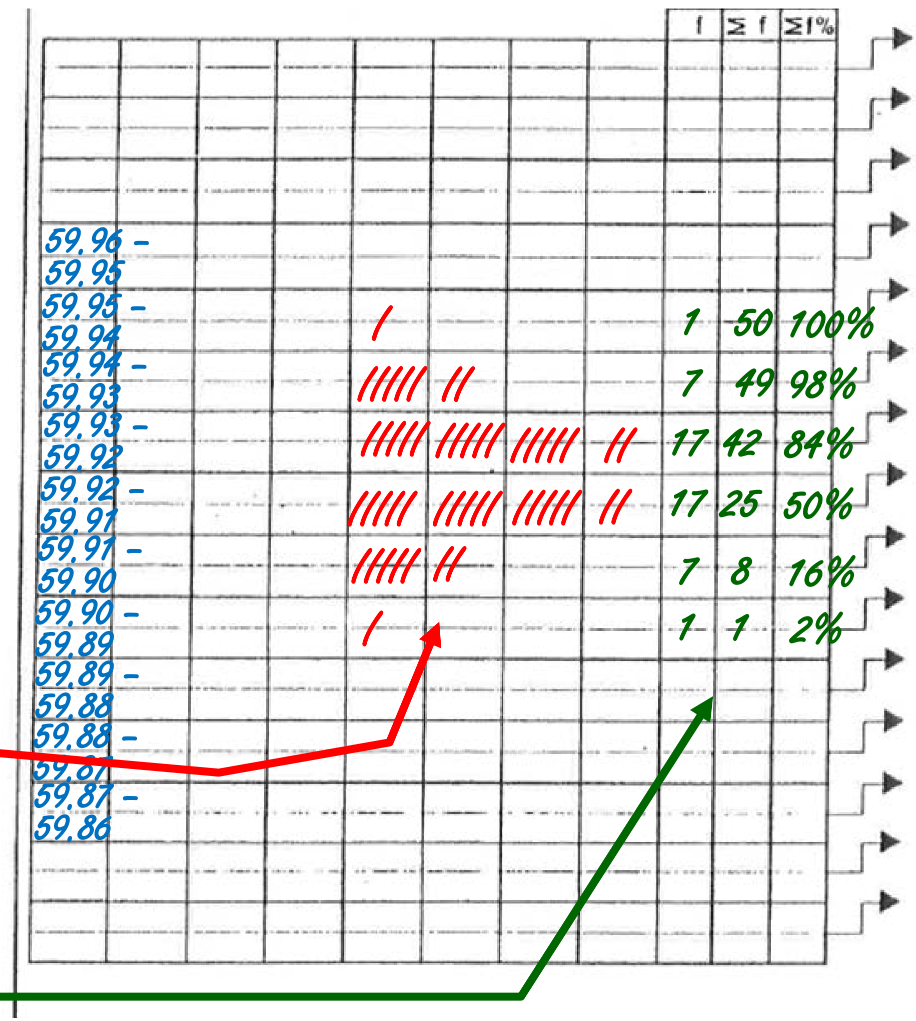
Study performed at: Location / factory / operation where study was done			
Characteristic: H9/e9 Shaft	Dimension: 60mm Nominal	Operation:	Standard Deviation:
Part No: Part Number	Name: Part or assembly name (not your name!)		

2. Collect (or copy across) the data into the table

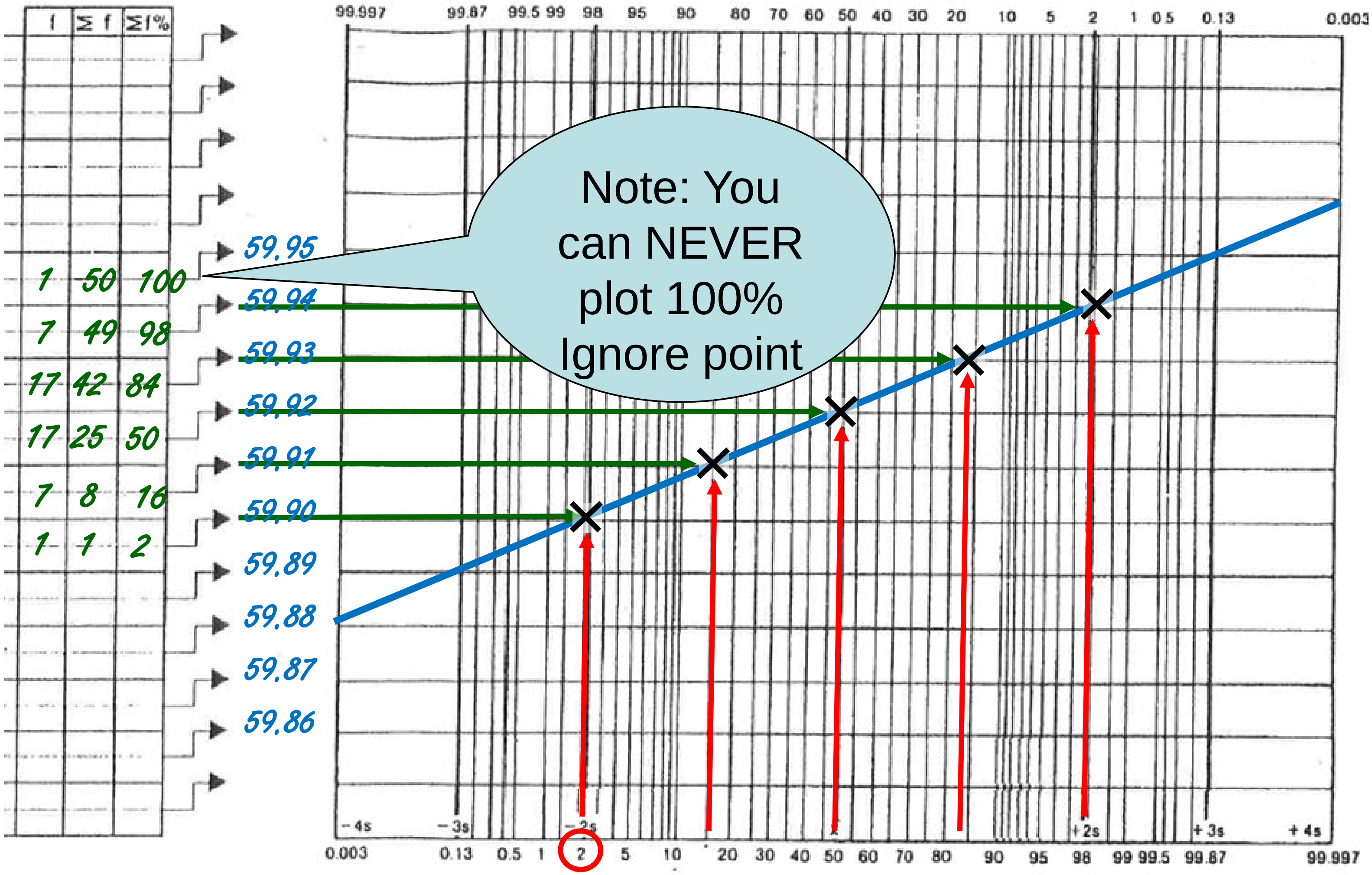
Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
1 59.934	6 59.929	11 59.928	16 59.905	21 59.933	26 59.910	31 59.914	36 59.914	41 59.919	46 59.923
2 59.901	7 59.925	12 59.911	17 59.906	22 59.937	27 59.912	32 59.930	37 59.908	42 59.922	47 59.912
3 59.926	8 59.921	13 59.919	18 59.921	23 59.917	28 59.923	33 59.897	38 59.926	43 59.919	48 59.902
4 59.912	9 59.913	14 59.922	19 59.945	24 59.917	29 59.906	34 59.915	39 59.923	44 59.932	49 59.936
5 59.915	10 59.918	15 59.939	20 59.924	25 59.936	30 59.926	35 59.914	40 59.912	45 59.928	50 59.925

Capability Chart (continued)

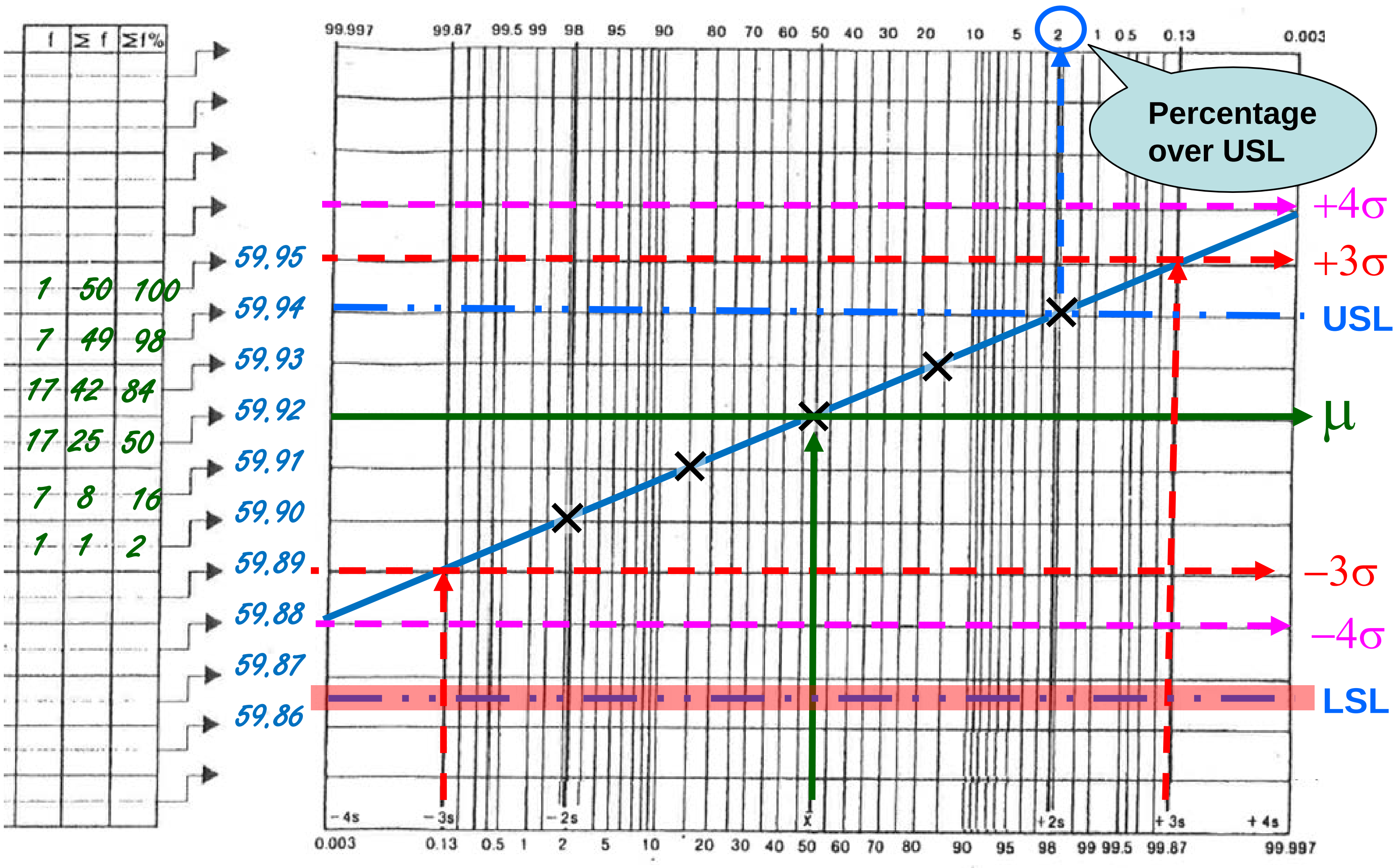
- Find the Max and Min of your data OR use the Upper and Lower Spec Limits
  (59.95mm, 59.86mm)
- Decide on your 'bin' size
  (0.01mm -> 59.86, 59.87, 59.88,...)
- Write the 'bins' onto the form
- Record the frequency in each bin
- Analyse the cumulative numbers and convert to percentage



Capability Chart (continued)



Capability Chart (continued 2)

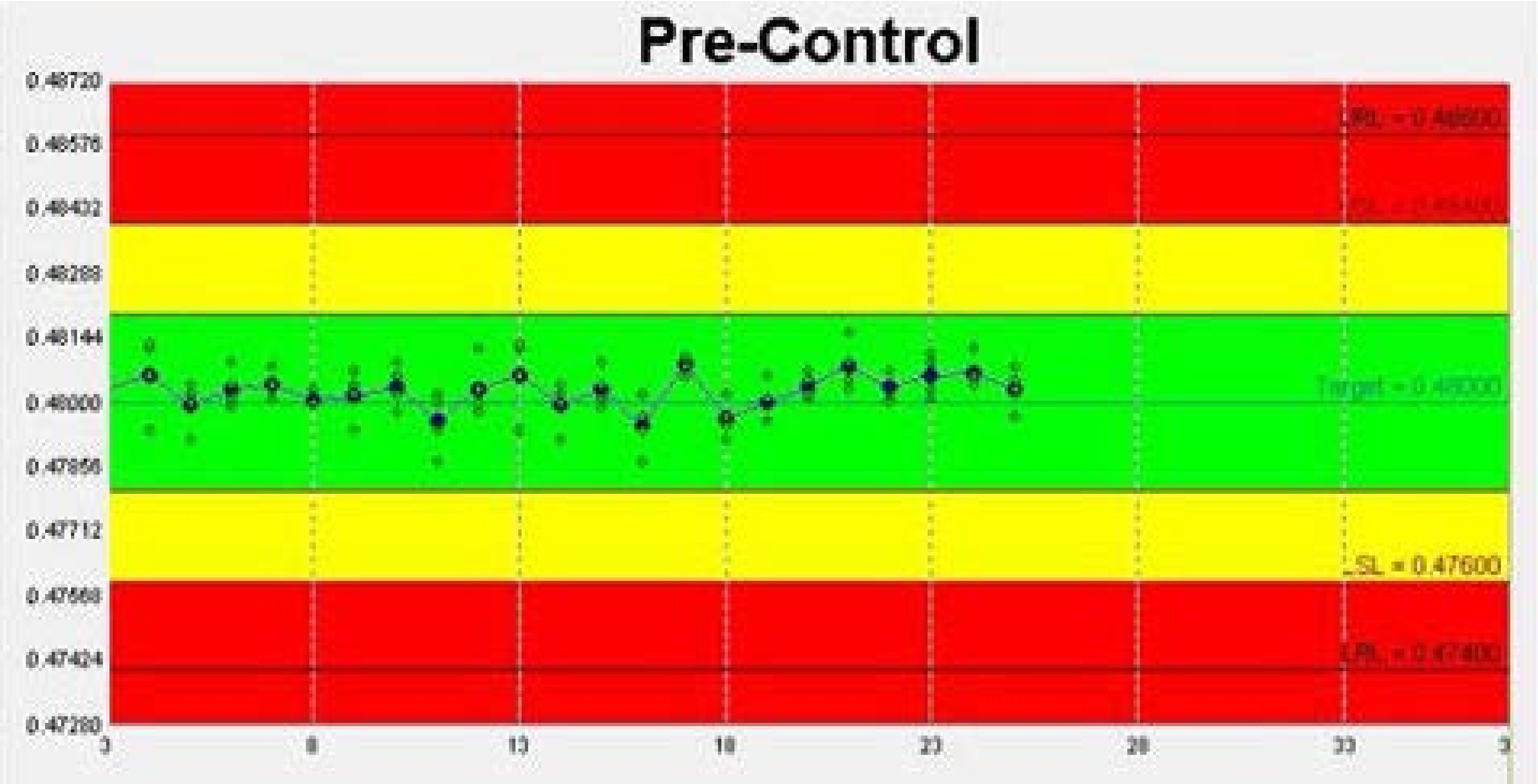


Finally complete the findings box…

Estimated out of tolerance	Specified tolerance	59.866mm (LSL) 59.940mm (USL)	Target value	59.903mm
	Estimated capability (8s)	0.080mm (8σ)	Estimated mean	59.920mm
Top 2.0 % Bottom 0.0 %	Capability index	=0.06 (6σ)	$C_p = (USL - LSL) / 6\sigma = 1.233$	
Study performed by :	D. J. Bremner			
Name	Signature		Date	YYYY/MM/DD

- We have now produced important information on the process at a single point in time
- We could use this as a 'snapshot' of the process and hope it remains the same or….

Use Statistical Process Control (SPC) Charts



- If we plot the information over the time the process is running, we can set ‘intelligent’ process limits using SPC

Class Opportunity

Working in pairs…

Use ONE of the data sets on the following sheet to complete a control chart as shown:-

Follow the steps carefully to complete the chart

You have 10 minutes to complete the task

Student datasets for Process Capability

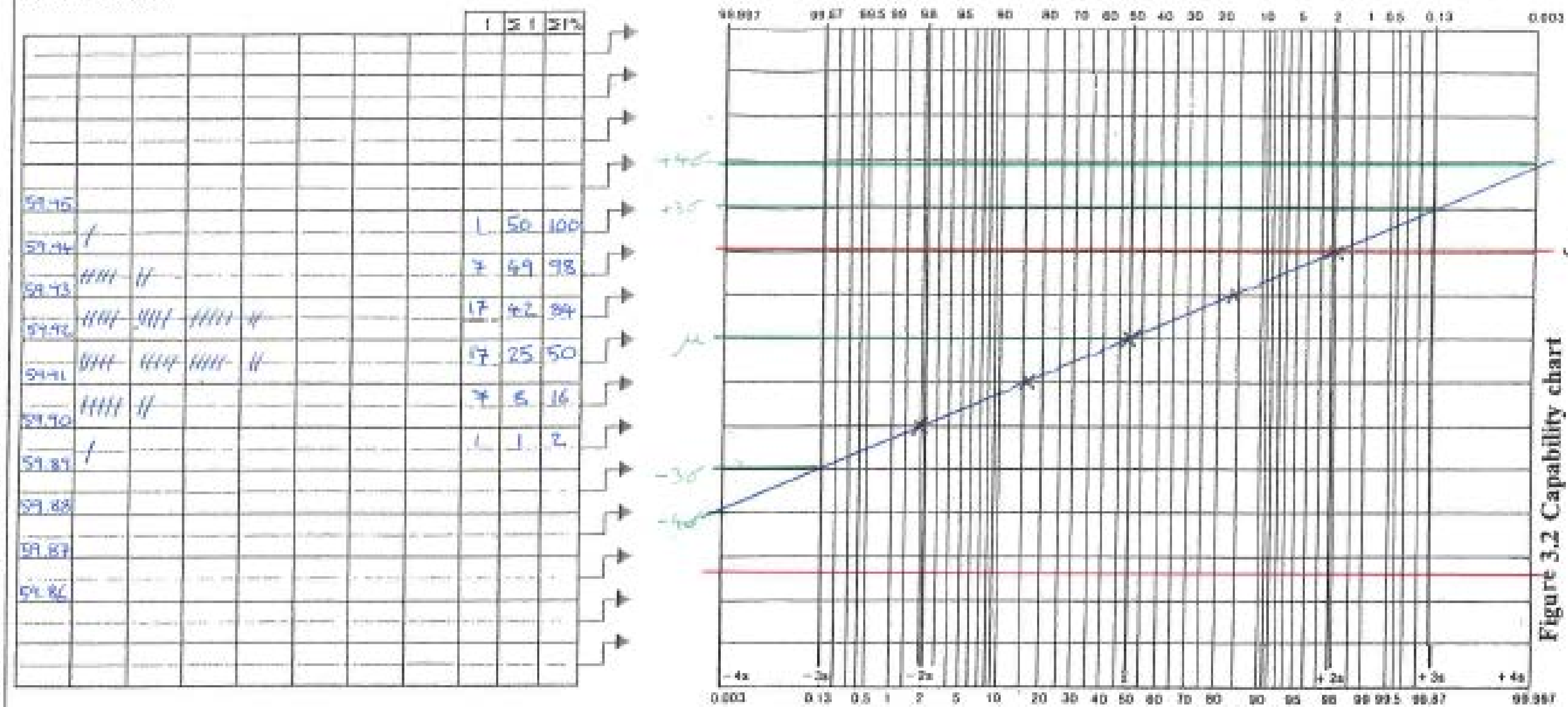
120K Resistor									
120.028	120.018	120.016	119.970	120.026	119.980	119.988	119.988	119.998	120.006
119.962	120.010	119.982	119.972	120.034	119.984	120.020	119.976	120.004	119.984
120.012	120.002	119.998	120.002	119.994	120.006	119.954	120.012	120.024	120.032
119.984	119.986	120.050	119.994	119.972	119.990	119.990	120.006	120.024	120.032
119.990	119.996	120.038	120.008	120.032	120.012	119.988	119.984	120.016	120.010
Amplifier x4 Gain									
4.00093	4.00060	4.00053	3.99900	4.00087	3.99933	3.99960	3.99960	3.99993	4.00020
3.99873	4.00033	3.99940	3.99907	4.00113	3.99947	4.00067	3.99920	4.00013	3.99947
4.00040	4.00007	3.99993	4.00007	3.99980	4.00020	3.99847	4.00040	4.00080	4.00107
3.99947	3.99953	4.00167	3.99980	3.99907	3.99967	3.99967	4.00020	4.00080	4.00107
3.99967	3.99987	4.00127	4.00027	4.00107	4.00040	3.99960	3.99947	4.00053	4.00033
Amplifier x10 gain									
10.0070	10.0045	10.0040	9.9925	10.0065	9.9950	9.9970	9.9970	9.9995	10.0015
9.9905	10.0025	9.9955	9.9930	10.0085	9.9960	10.0050	9.9940	10.0010	9.9960
10.0030	10.0005	9.9995	10.0005	9.9985	10.0015	9.9885	10.0030	10.0060	10.0080
9.9960	9.9965	10.0125	9.9985	9.9930	9.9975	9.9975	10.0015	10.0060	10.0080
9.9975	9.9990	10.0095	10.0020	10.0080	10.0030	9.9970	9.9960	10.0040	10.0025

Find the mean (μ), +/-1σ, and +/-3σ for ONE of the above data sets using a capability chart.

Capability Study

For Normal distribution

Study performed at:			
Characteristic: H9/e9 Shaft	Dimension: 60mm Nominal	Operation:	Standard Deviation:
Part No:	Name:		

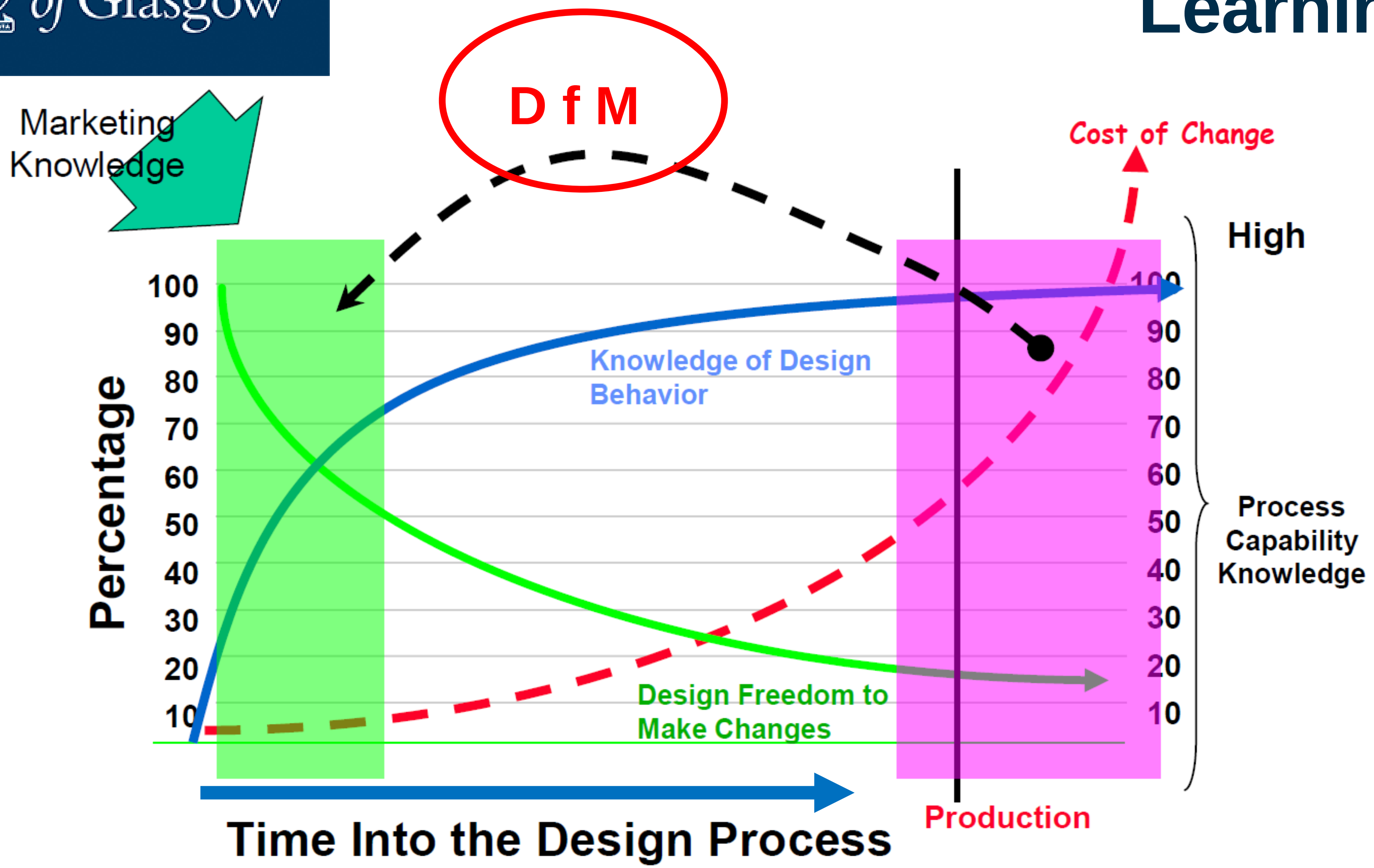


Value	Value	Value	Value	Value	Value	Value	Value	Value	Value
1 59.934	6 59.929	11 59.928	16 59.905	21 59.933	26 59.910	31 59.914	36 59.914	41 59.919	46 59.923
2 59.901	7 59.925	12 59.911	17 59.906	22 59.937	27 59.912	32 59.930	37 59.908	42 59.922	47 59.912
3 59.926	8 59.921	13 59.919	18 59.921	23 59.917	28 59.923	33 59.897	38 59.926	43 59.919	48 59.902
4 59.912	9 59.913	14 59.922	19 59.945	24 59.917	29 59.906	34 59.915	39 59.923	44 59.932	49 59.936
5 59.915	10 59.918	15 59.939	20 59.924	25 59.936	30 59.926	35 59.914	40 59.912	45 59.926	50 59.925

Estimated out of tolerance	Specified tolerance 59.866/59.940	Target value 59.903
	Estimated capability (8s) 0.080 (0.060)	Estimated mean 59.920
Top 2.0 % Bottom 0 %	Capability index 0.925 (1.23)	
Study performed by: J. P. Shackleton		
Name	Signature	Date

Fully populated Process Capability chart

Process Knowledge and Learning



We use our process capability knowledge to influence the quality of the products we design == better customer satisfaction

Summary

- We have looked at the importance of Design for Manufacturing (DfM)
- We have shown the importance of understanding the impact of manufacturing variation on product quality / specifications
- We have shown how to quantify the impact of manufacturing spread on final product quality
- Next lecture
  - How can we incorporate process capability to produce better / more productive designs
  - … and therefore improve manufacturing costs

Reading List

- Capability Worksheet
- Normal Distribution Tables_DJB
- Process Capability Studies Winton_1999
- Using Standardised Normal Tables


University of Glasgow
Thank you
谢谢