Quality Assurance in Measurement

Module 5 - The Practice for Quality Measurement

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CONTENTS

Introduction

We have examined the meaning of that popular term "Quality of Measurement" and the foundations needed to establish a quality measuring system. Now, we pursue these ideas further by discussing such practical matters as:

- The organization for measurement
- The procurement and acceptability of measuring devices
- Standards and calibration
- Statistical process control in metrology

1.0 The Organisation for Measurement

No matter how much effort, money and time is lavished on measuring processes, without proper organization the final result can only be chaos, in one form or another! The "Measurement Process Documentary Structure" (MPDS) is a document devised to establish a sensible organization for all measurement processes (MP). Every MPDS consists of two main components:

- Standards relative to several measurement processes
- Dossiers specific to each measurement process

Figure 1.1 schematically demonstrates the organization of a typical MPDS.

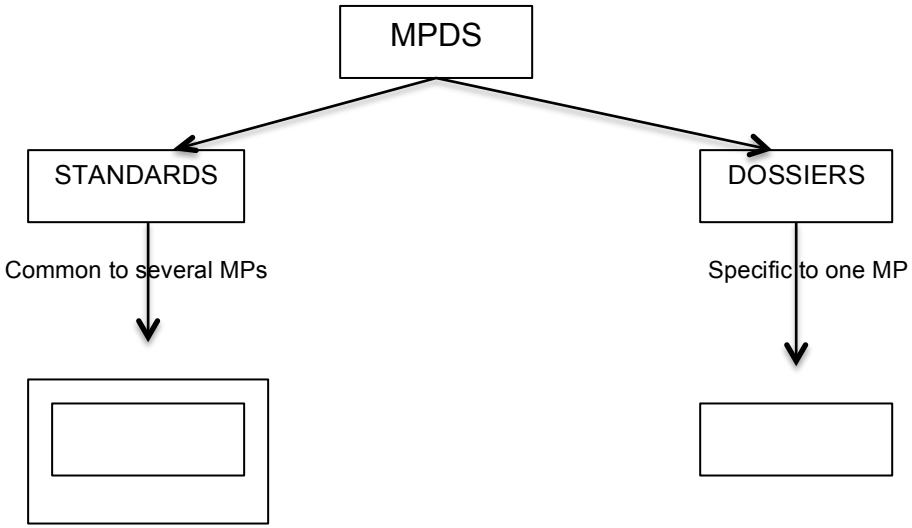


Figure 1.1

The Standards contain general information concerning all measurement processes or even just one type of measurement process. It is essential that they contain:

(a) Quality of Measurement standards, such as quality of measurement procedures, identification of instruments and service record sheets
(b) Standards that are specific to each department

The 12 dossiers that make up the MPDS are shown schematically in Figure 1.2. Observe that these dossiers are split into three subgroups, namely

- development,
- industrialisation, and
- use.

Figure 1.2

<table>
<tr><th></th><th>SUBGROUP</th><th>DOSSIERS</th></tr>
<tr><td>Central Source</td><td>Development</td><td>SPECIFICATION
STUDY APPROVAL DOSSIER</td></tr>
<tr><td>General Industry</td><td>Industrialisation

Use</td><td>Installation & Implementation Instructions
Reception Conformity
Approval Tag
Fiche Tech. Method Meas. Main Instr. Modif Sheet Meas Qual.</td></tr>
<tr><td>Local Industry</td><td>Use</td><td>METHOD OF WORK</td></tr>
</table>

Below, we give a brief description of each of these dossiers.

Specification

This specifies the needs or the objective of the measurement process, such as the definition of the quantity to be measured, the tolerances, the conditions under which the measurements are to be made, and so on.

Study

The Study dossier records the results of the capability study of the measurement process.

Qualification
Here, we define the tests required to provide the proof that the measurement process and following generations meet the prescribed specification.

Clearly this dossier contains the necessary installation instructions as provided by the manufacturer and, possibly, as modified by the customer.

Reception Conformity
The Reception Conformity dossier contains the details of the tests that provide the proof that all measurement processes installed on site are identical to the measurement process that has been qualified.

Approval Training
This contains the definition of the contents of the training and criteria by which it is qualified.

Fiche Technique
In this dossier, a summary of the performance of the measurement process (e.g. the uncertainty of measurement, allowable limits of variation of ambient conditions) are held.

Method of Measurement
This contains all the theoretical considerations and practical operations together with all the conditions necessary to carry out a measurement and for controlling the uncertainty of measurement.

Maintenance Instructions
As the name implies, this dossier contains all the instructions for maintenance essential for monitoring the performance of the instrument.

Modification Sheets
This is a most important dossier, for it contains the traceability for all modifications to a measurement process. Without it, there can be no assurance of traceability.

Quality of Measurement
This dossier complements the reception conformity dossier. It provides the proof that the performance of a measurement process is maintained over time. Thus, it contains procedures for:

(a) determining the conventional true value;
(b) the calibration of instruments;
(c) confirming the capability of the measurement process and its control;
(d) monitoring the quality of measurement.

Method of Work

This dossier is given to the operator along with the instrument. It gives the details of procedures necessary to perform the measurement in a particular location. It is the only dossier that is always written locally.

It is natural to ask: "Are the above dossiers always necessary?". The simple answer is "no" since the complete set of dossiers are really only needed when we have a complex measurement process. Whenever we have a simple measurement process there are two lower levels of documentation available to us. A simple guide as to which of the three possible levels is appropriate for a particular measurement process is given below.

SYSTEM	USES
FULL	Pressures and temperatures Product thickness with Beta gauge
MEDIUM	Measuring length of wires using a digital vernier reading to 1/100th. Melting point on accelerator and anti-oxidant
ABRIDGED	Turn-up pressure Measuring maximum heating temperature of a furnace.

The content of the three types of reference system is given below.

		REFERENCE SYSTEM	
DOSSIERS	Full	Medium	Abridged
Specification	*	*	*
Study	*		
Approval	*		
Installation	*		
Instruction			
Reception	*	*	*
Conformity			
Approval	*	*	
Training (3)			
Fiche *			
Technique			

Method of Measurement	*	(4)	(4)
Maintenance Instructions	*		
Modification Sheet	*		
Quality of Measurement	*	*	
Method of Work (1)	*	*	*

NOTES:
(1) The Method of work is always drafted locally
{2) All the dossiers for these measurement processes can be drafted locally
{3) The list of approved operators will be drafted locally
(4) The Method of Measurement is not drafted separately but is included in the Method of Work

2.0 Procurement and Acceptability of Measuring Devices

Irrespective of any manufacturer's claims about the performance of their measuring instruments, it is essential for you as the customer to undertake a feasibility and capability study (using the statistical techniques from Module 3 and the SPC ideas given later in this Module) of the instrument under factory operating conditions. Naturally, this should be done before the equipment is purchased! From such a study, we should gain information regarding the stability, capability, repeatability, accuracy and uncertainty of the equipment. Furthermore, you should always be more than satisfied on the traceability (see later) of the measuring instrument.

At this point, we need to consider what action, and by whom, should be taken to develop the quality of measurements. In most companies the responsibility for developing the quality of measurements rests with that Quality Improvement Team (QIT) tasked with investigating the particular measurement problem. The steps to be taken by the QIT are based on ISO 9002 (see Module 5) and on the Abridged Reference System of MPDS.

Below we give the main steps the QIT needs to undertake to implement Quality of Measurement.

1. Identify the critical measurements that directly affect the quality of the product.
2. Write a specification for the requirements of the measurement process. This should include the quantity to be measured, the range, the tolerance, the capability indicators and so on.
3. Define the requirements for the measurement process which are necessary for Quality of Measurement; this should include the layout, the ancillary equipment, the environment etc. The level of the MPDS documentation required also needs to be specified.
4. Select the instrument required to do the job.

5. Before purchase, test the instrument for conformance to the manufacturer's specification. Use SPC techniques to study the capability etc. of the instrument in a working environment. The Reception Conformity dossier in the MPDS document should be completed.
6. Establish the traceability to National Standards.
7. Calibrate the instrument and determine its uncertainty of measurement.
8. Register the relevant details in the appropriate file.
9. If possible (and, if necessary) supply a conventional true value.
10. Write the method of work.
11. Write the verification procedure.
12. Specify the plan to monitor the Quality of Measurement.
13. Complete the MPDS dossiers.
14. Construct a maintenance plan.
15. Train and validate the operator(s).
16. Develop the rules of action for dealing with non-conformities.

Of course, we need a procedure for maintaining the Quality of Measurement. Below we give the two main ingredients of such a procedure.

- Maintain the instruments.
- Monitor the Quality of Measurement by:

a) instrument verification;
b) recalling and calibrating at appropriate time intervals (remember to record such action in the instrument documentation);
c) using SPC (whenever necessary).

It should be noted that, in general, the responsibility for Quality of Measurement rests with the particular department requiring the measurement. Furthermore, we should remind ourselves that the instrument is the responsibility of the user.

3.0 Standards and Calibration

In this section we look at two very important questions: "What do we mean by 'Standards'?" and "Why calibrate?". The word 'Standards' in the first question can in fact mean one of many things and so it is very appropriate to discuss this issue.

There are four main Standards we can identify and below we give details of these.

1. **Measurement Standard** This can be a material measure or a measuring instrument or even a measuring system. The intention is to define or reproduce one or more known values of a quantity so as to communicate them, by comparison, to other measuring instruments. Common examples of such standards are:

- 1 kg mass standard
- standard gauge block
- 100 standard resistor

- saturated Weston standard cell
- standard ammeter
- caesium atomic frequency standard.

2. **Reference Standard** This is a standard from which measurements made in a particular location are derived. Naturally, it should be of the highest metrological quality available at that location.

3. **Working Standard** A working standard is used in everyday life to routinely check, or even calibrate, material measures and instruments. It is usually calibrated against a reference standard.

4. **Transfer Standard** The transfer standard is used as an "intermediary" to compare standards, material measures or measuring instruments. Whenever this comparison device is not strictly a standard we should use the term "transfer device"; an example is the case of adjustable calipers used to compare end standards.

What do we mean by "calibration"? Calibration can be considered as a set of operations that establish, under prescribed conditions, the relationship between values indicated by a measuring instrument (or system) and the corresponding known values of the quantity being measured (sometimes called the measurand).

Let us now turn to the second question "Why calibrate?" The objective of doing a calibration is to check the performance of the measuring instrument both before being commissioned and during its operating life. If this latter action is carried out at regular intervals then the results should be recorded on a run chart or a control chart; this will enable variation, trends (if any) to be detected.

Of course, we should ask "What instrument should we use for a calibration?". Naturally, in order to ensure that the estimated uncertainty of measurement is reliable the calibration must be carried out using a standard that is traceable, through an unbroken chain of comparisons, to National Standards. The act of calibrating a calibrator against a more accurate calibrator is often called "moving up the traceability ladder". As an example of this, Figure 3.1 shows the main steps in the traceability ladder between an Industrial weighing device and the International Standard Kilogramme.

Figure 3.1 - Uncertainty of Calibrated Instruments

International Standard Kilogramme (Paris)
National Primary Standard kg (London)
National Secondary Standard kg (London) National Transfer Standard Weight (London) Local Standard Weight
Your Factory Standard Weight
Your Measuring Instrument

Not surprisingly, calibrated instruments have a fundamental role in metrology, and so we need to estimate their uncertainty of measurement! There are a number of potential sources of uncertainty that can combine to produce a final assessment of the uncertainty of measurement. These factors are briefly discussed below.

1. The repeatability of the instrument (R_i). This is calculated from a repeatability test on the instrument.

2. The repeatability of the calibrator (R_c). The actual method of determining R_c depends on the type of calibration process used. There are three forms of calibration to consider: (a) the static standard, (b) the reference standard, and (c) the combination standard.

(a) The static standard is the term used for a quantity of substance that is assumed not to vary. Examples of such a standard are (i) a standard weight used for calibrating a weighing Instrument, (ii) a block of metal used for calibrating a micrometer and (iii) a fluid used to calibrate a viscometer. In each case, it is assumed that the appropriate physical property (mass, thickness and viscosity in the above examples) does not vary to any great extent. Thus it is assumed that the random uncertainty R_c of a static standard is zero.

(b) The reference standard is an instrument capable of measuring the same quantity as the instrument under test but (hopefully!) with a greater accuracy. The repeatability R_c of such an instrument can be determined in the usual way.

(c) In a combination calibrator, at least two different quantities are measured together and their values combined according to some physical law to produce the filial measured value. For example, we may measure the voltage and current in order to calibrate a wattmeter. The uncertainty of measurement can then be calculated using the techniques in Module 5.

3. The systematic uncertainty of the calibrator (S_c). Generally, this is determined by the company supplying the calibrator. Interestingly, they will have derived that value by calibrating your calibrator against an even more accurate device held either by them or by the next organization up the traceability ladder.

4. The random uncertainty of the link between the calibrator and the instrument (R_l). If the link between the calibrator and the instrument is static then R_l is usually assumed to be zero. However, there are situations where R_l could be quite sizeable; for example, if two fluid flowmeters are installed in the same test pipe to measure the gas flow then random pressure pulsations will cause the two meters to be affected differently. The usual recommendation in such cases is to design the system so as to minimize R_l and subsequently take it to be zero (even if R_l is not zero its effect is somewhat compensated for by the combined effects of R_i and R_c).

5. The systematic uncertainty in the link between the calibrator and the instrument (S_i). There is no way this effect can be measured and so it is estimated (using experience!).

The overall uncertainty of measurement is calculated in the now familiar way:

$$3\ \sqrt{\{R_i^{\,2} + R_c^{\,2} + R_1^{\,2} + S_c^{\,2} + S_i^{\,2}\}}.$$

4.0 Statistical Process Control (SPC)

In the 1920s, Dr Walter Shewhart devised a method of classifying process variation that plays a crucial role in improving processes.

Shewhart had worked for some 18 months at Western Electric and then moved to the recently founded Bell Laboratories in New York. In Dr Deming's words the story continues.

"Part of Western Electric's business involved making equipment for telephone systems. The aim was, of course, reliability: to make things alike so that people could depend on them. Western Electric had the ambition to be able to advertise using the phrase as alike as two telephones. But they found that, the harder they tried to shrink variation, the larger it got. When any kind of error, mistake or accident occurred, they went to work on it to try to correct it. It was a noble aim. There was only one trouble. Things got worse.

Eventually, the problem went to Dr Walter Shewhart at the Bell Laboratories. Dr Shewhart worked on the problem. He became aware of two kinds of mistake:

1. *Treating a fault, complaint, mistake, accident as if it came from a **special cause** when in fact there was nothing special at all, that is, when it came from the system - from random variation due to common causes.*

2. *Treating any of the above as if it came from a **common cause** when in fact it was due to a special cause.*

What difference does it make? All the difference between failure and success.

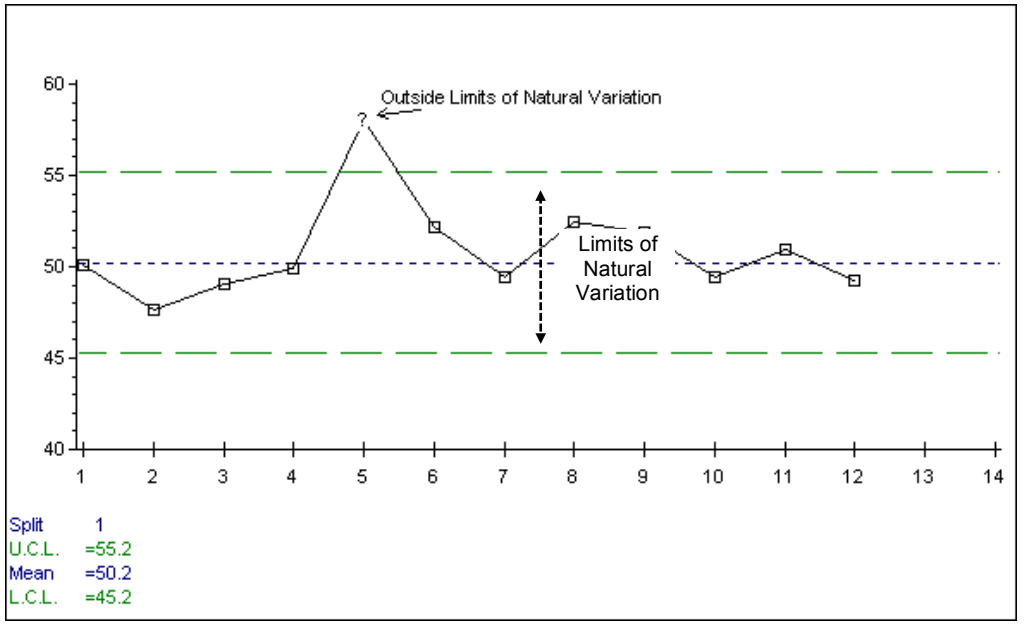
Dr Shewhart decided that this was the route of Western Electric's problems - they were failing to understand the difference between common causes and special causes, and that mixing them up makes things worse. It is pretty important that we understand those two kinds of mistakes. Sure we don't like mistakes, complaints from customers, accidents - but if we weigh in at them without understanding, then we make things worse. This is easy to prove by mathematics." *(Dr W Edwards Deming, Versailles July 1989)*

Shewhart's work at the Bell Laboratories led to him realising that variability can be regarded as being either within or outside the limits set by chance. If the variability was outside these limits then he believed that the source of variability could be identified. He made the following distinction between these two types of variation:

"While every process displays variation,
some processes display controlled variation,
while others display uncontrolled variation."

Shewhart regarded controlled variation as that produced by a stable and consistent pattern of variation over time. In other words, it is attributed to "chance". On the other hand, he classed uncontrolled variation as being variation with no consistency over time. Shewhart attributed these changes in the pattern of variation to "assignable" causes.

Not only did Shewhart classify variation as “chance” or “assignable” (and why it is important to understand the difference between them), he gave us the way of distinguishing between them using what we now call the Control Chart - one is shown below.



4.0.1 Special and Common Causes of Variation

In the 1950’s Dr Deming reworded Shewhart's original classifications of variation. Shewhart had emphasised the sources of variation with his assignable causes and chance causes; assignable causes being sources of variation that do not belong to the system while chance causes are due to the system and are always present. These terms emphasise the source of variation but Deming wished to use terms that focused attention onwho was responsible for doing something about the variation. It was for this reason that he introduced the terms **special** and **common** causes of variation.

"Shewhart used the term assignable cause of variation where I use the term special cause. I prefer the adjective special for a cause that is specific to some group of workers, or to a particular production worker, or to a specific machine, or to a specific local condition. The word to use is not important; the concept is, and this is one of the great contributions that Dr Shewhart gave to the world."

Dr W E Deming "Out of the Crisis"

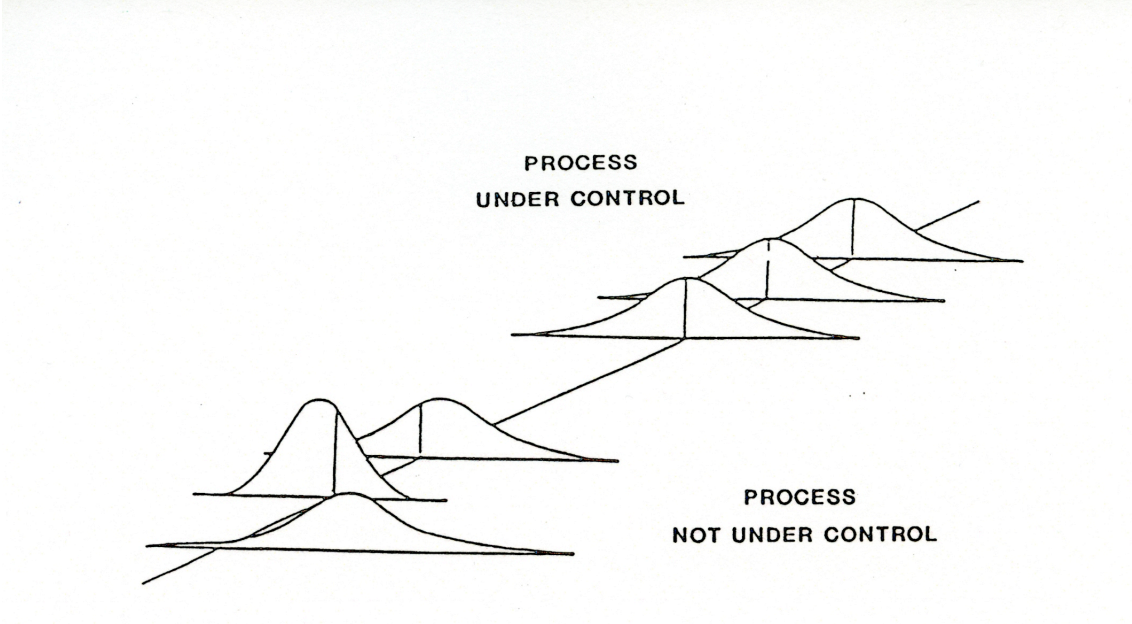
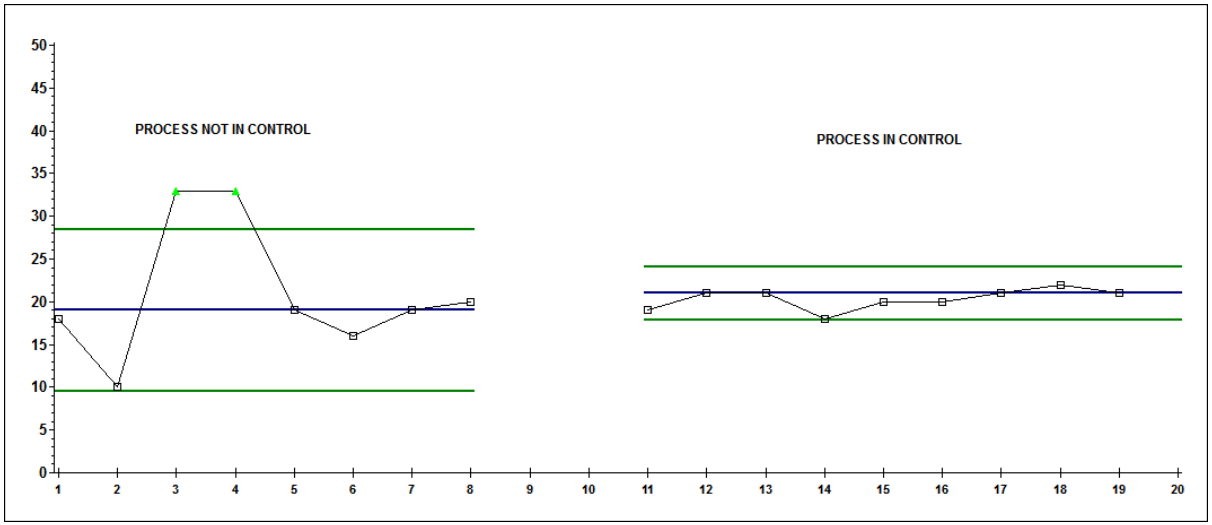


Figure 4.1

It is interesting to compare each of the diagrams in Figure 4.1 with the corresponding "typical" controls charts for these situations. These are given in Figure 4.2 below.

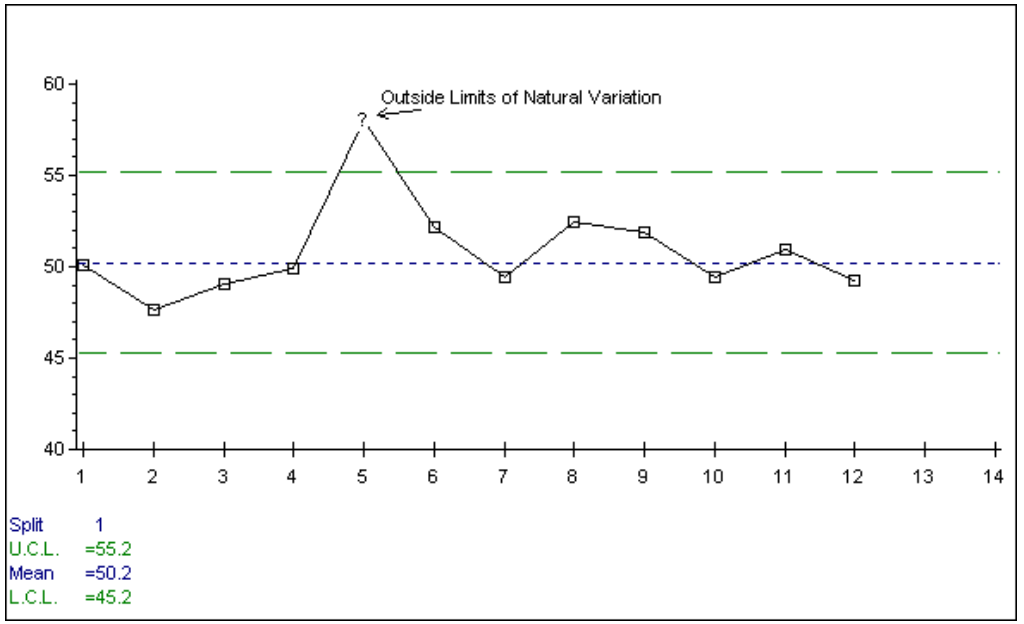


We should remember that the control chart limits shown above are there simply as guide lines. They help us in the assessment of the amount of variation to be expected if only variation from common causes were present.

A process that is exhibiting only common causes of variation has a stable behavioural pattern which enables us to predict the future behaviour of the process — in the sense that, unless the process changes, the variation will continue to lie between the control limits. On the other hand, special causes of variation, whether they are trends or just odd happenings, destroy this stable pattern.

4.0.2 Control Chart Limits

The idea of the limits is that points within them are regarded as being due to process variation (i.e. chance variation) while any points outside are probably due to special (assignable) causes.



As we shall later see, the actual width of the limits depends entirely on the amount of variation in the process - the limits are not "man made" (as with tolerance and specification limits).

Control chart limits only serve as guidelines. They help us in the assessment of the amount of variation to be expected if only variation from common causes was present. This means that the control limits should only be calculated on data from processes having some semblance of stability.

Shewhart's Recommended Limits

Shewhart recommended control limits to be set at 3 standard deviations either side of the mean line. His discoveries led to several reasons for the choice of these limits[1].

1. To use limits based on exact probability theory is suggesting a situation that can be precisely modelled by theory which is never the case!
2. He found empirically that values lying more than 3 standard deviations from the mean were there for a "special reason" i.e. he could assign a cause to them.
3. A statistical result due to Tchbeycheff that implies that at least 8/9 (i.e. practically 90%) of all the data — irrespective of its underlying distribution — lie within 3 standard deviations of the mean.

Thus to use the 3-standard deviation limits as "control" or guidelines makes a lot of practical sense. In fact, Shewhart's reason for choosing “3 standard deviation limits” was simply that it seems to an acceptable economic value — from the point of view of not missing special causes (limits too wide) or interfering with common cause variation (limits too narrow).

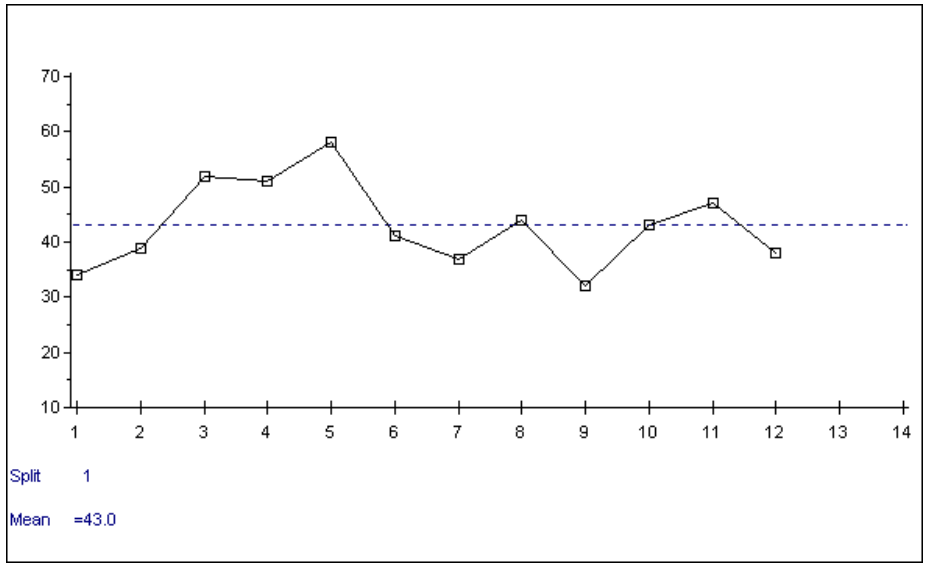
4.1 Control Charts for Individual Values (Single Measurements)

A frequent situation, particularly in a non-manufacturing environment or in short production runs, is where the data are *individual* values taken over a period of time.

To construct the control limits, we need some method of estimating the process variation without any trends and special causes interfering. With individual data values we estimate the underlying process variation by calculating moving ranges which are differences between the first and second observation, the second and the third, and so on. The following example demonstrates the calculation.

Job Number	Time	Moving Range
1	34	—
2	39	5
3	52	13
4	51	1
5	58	7
6	41	17
7	37	4
8	44	7
9	32	12
10	43	11
11	47	4
12	38	9
Total	516	90
Mean	43.0	8.2

The run chart for these data is given below.



The relationship between the mean of the moving ranges (which we will denote by $\overline{MR}$) and the process standard deviation is:

$$\text{process standard deviation} = \frac{\text{mean moving range}}{1.128} = \overline{MR}/1.128$$

which gives

$$3*\text{standard deviation} = 3*\overline{MR}/1.128 = 2.66*\overline{MR}$$

for the gap on either side of the mean line.

[Note: the above constant 1.128 is a conversion factor obtained from statistical theory]

So, using the formula given earlier

UPPER LIMIT	Mean + 3 * Standard Deviation
LOWER LIMIT	Mean – 3 * Standard Deviation

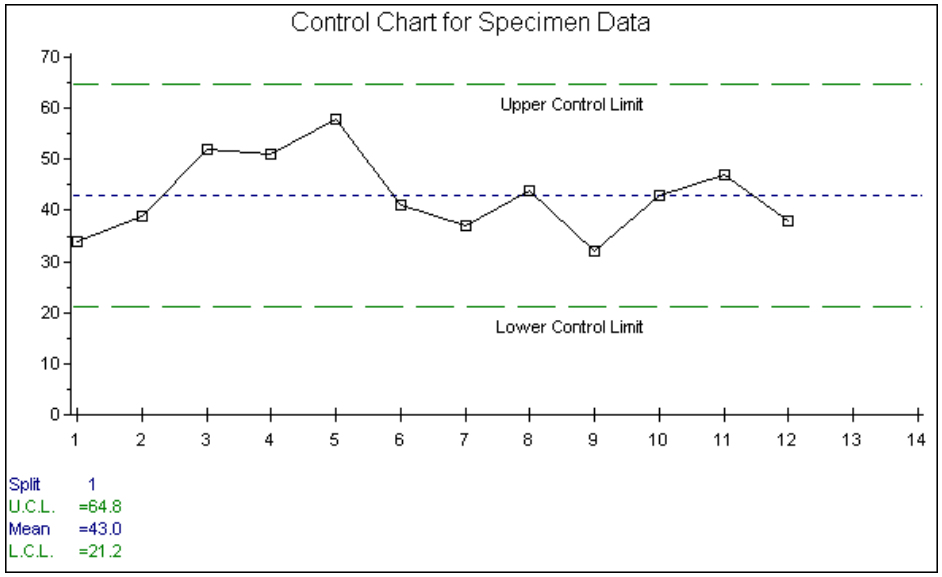
we have as the 3-standard deviation limits for single measurement data:

UPPER CONTROL LIMIT	$\overline{X} + 3^* \overline{MR}/1.128$ $= \overline{X} + 2.66^* \overline{MR}$
LOWER CONTROL LIMIT	$\overline{X} - 3^* \overline{MR}/1.128$ $= \overline{X} - 2.66^* \overline{MR}$

Using these formulae, we obtain for the data given above:

Upper control limit = 64.8
Mean = 43.0
Lower control limit = 21.2

and the resulting control chart is below.



4.2 Control Charts For Means & Ranges

In contrast to the previous measurement data where single values were obtained one at a time, we now consider the case where several measurements are grouped to form a **subgroup**. This enables us to construct control charts for both the subgroup means and ranges.

4.2.1 Charts for the Subgroup Means and Ranges

Using ideas similar to those for calculating limits for individual measurements, we can construct control limits for the situation where subgroups (more than 1 measurement) are taken. The control charts we can construct are for the:

- ***subgroup means***, $\overline{X}$ — which monitors the behaviour of the subgroup means over time (trends, shifts, becoming more/less erratic)
- ***subgroup ranges***, R — which keep us informed of the consistency within the subgroups

We shall call the mean of all the individual observations the **overall mean** and denote it by $\overline{\overline{X}}$ - it is also called the "**mean of the means**".

The process variation is estimated from the mean ($\bar{R}$) of the subgroup ranges — which is similar to the idea we used for individual measurements. The basic formulae for the limits follow the same format as before and are:

CONTROL LIMITS FOR SUBGROUP MEANS

UPPER LIMIT	$\bar{\bar{X}} + A_2 \bar{R}$
LOWER LIMIT	$\bar{\bar{X}} - A_2 \bar{R}$

where the conversion factor A_2 depends on the subgroup size, n, and is given in the table below

CONTROL LIMITS FOR SUBGROUP RANGE

UPPER LIMIT	$D_4\bar{R}$
LOWER LIMIT	$D_3\bar{R}$

where the conversion factors D_3 and D_4 are given in the table below.

Control Chart Constants

	Subgroup Means	Subgroup Ranges	
n	A_2	D_3	D_4
1	2.660	—	—
2	1.880	—	3.27
3	1.020	—	2.58
4	0.730	—	2.28
5	0.580	—	2.12
6	0.480	—	2.00
7	0.420	0.08	1.92
8	0.370	0.14	1.86
9	0.340	0.18	1.82
10	0.308	0.223	1.777

At first sight, it appears that the limits for the ranges are not symmetrical (as they are for the means) and so are not based on Shewhart's idea of ±3*standard deviations. However, the limits **are** symmetrical — it's just that the version above is a mathematically shortened form! The original version for the limits is:

$$\text{Lower/Upper Limit} = \bar{r} \pm (1 - D_4)^* \bar{r}$$

which shortens to:

$$\text{Upper Limit} = \bar{r} - (1 - D_4)^* \bar{r} = D_4^* \bar{r}$$

and,

$$\text{Lower Limit} = \bar{r} + (1 - D_4)^* \bar{r} = (2 - D_4)^* \bar{r}, \text{ usually written as } D_3^* \bar{r}.$$

This explains why the lower limit for the ranges does not exist for subgroup sizes (n) less than 7 as then the lower limit would be negative which is not possible in the real world!

An Example: The data below are measurements (in mm.) relating to the width of a fabric. Ten subgroups, each of size 5, were taken over a certain period of time.

	1	2	3	4	5	6	7	8	9	10
	142	157	142	154	161	144	147	150	154	139
	155	146	147	154	145	150	150	150	153	152
	147	142	152	149	150	148	147	150	152	143
	153	148	145	154	151	151	146	151	151	140
	147	145	156	154	151	145	148	158	150	154
$\bar{x}$	148.8	147.6	148.4	153.0	151.6	147.6	147.6	151.8	152.0	145.6
R	13	15	14	5	16	7	4	8	4	15

For these data, the overall mean, $\bar{\bar{X}}$, = 149.4 and the mean range, $\bar{R}$, is 10.1.

Calculation of the Control Limits for the Subgroup Means

The Centre line is the overall mean, $\bar{\bar{X}}$ = 149.4 and for n = 5 the value of A2 is 0.580.

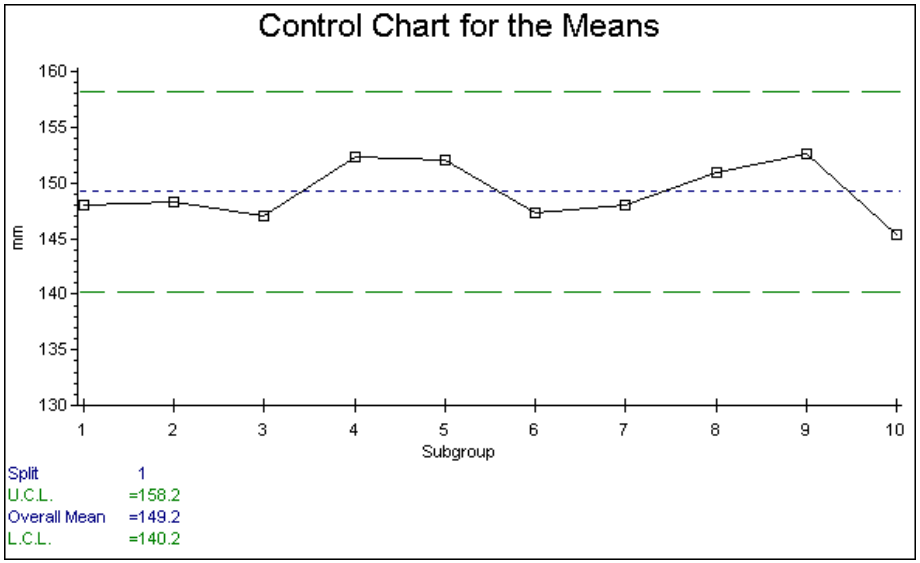
UPPER LIMIT	$\bar{\bar{X}} + A_2 \bar{R}$ = 149.4 + 0.580*10.1 = 155.2
LOWER LIMIT	$\bar{\bar{X}} - A_2 \bar{R}$ = 149.4 – 0.580*10.1 = 143.6

Calculation of the Control Limits for the Subgroup Ranges

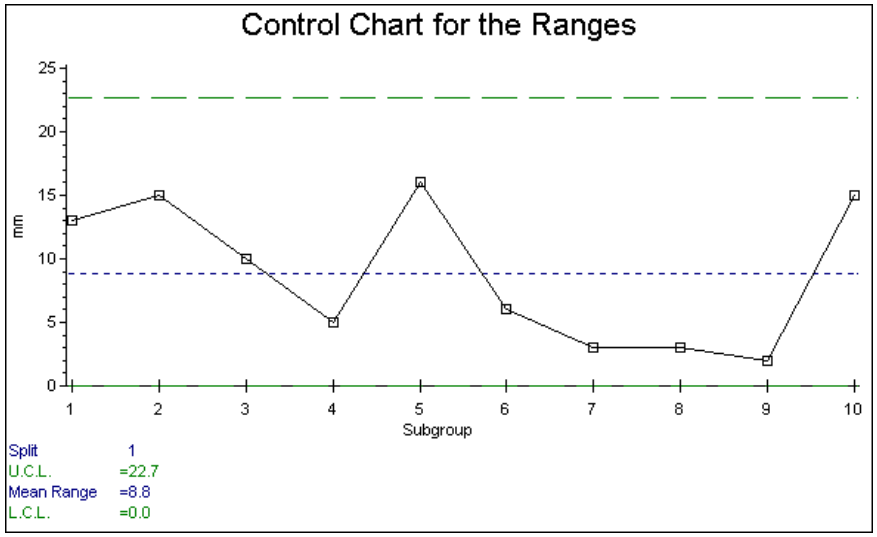
The Centre line is the mean of the subgroup ranges, $\overline{R}$ = 10.1 while from Table 1 we obtain D_4 = 2.12. Since D_3 is not defined the Lower Control Limit does not exist.

UPPER LIMIT	$D_4\overline{R}$ = 2.12*10.1 = 21.4

The resulting control charts for the subgroup means and ranges are given below.



The means control chart shows the means to be stable i.e. consistent over time.



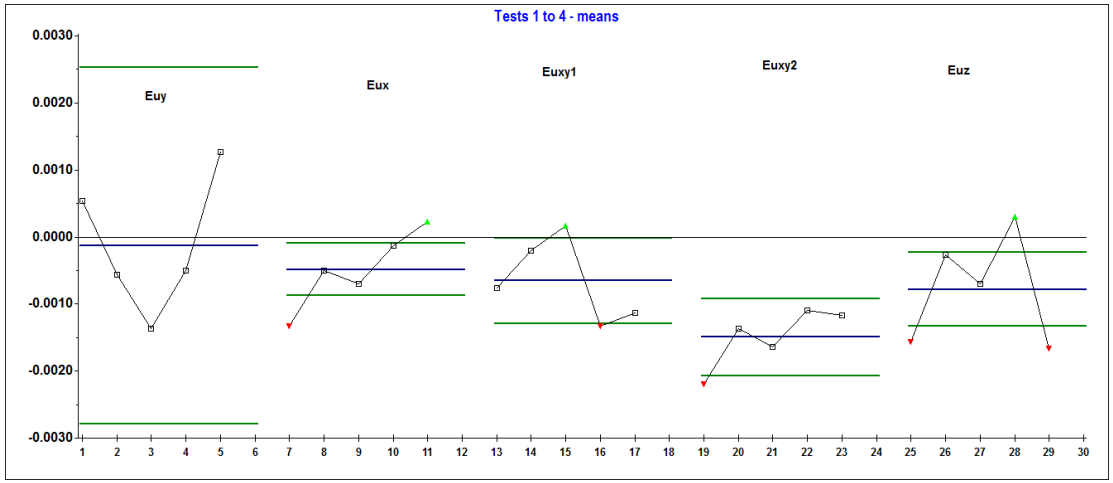
The control chart for the ranges shows the ranges to be “under control” although the variation (as measured by the range) within each subgroup is quite sizeable. Reducing the variation in the ranges to obtain more consistent fabric widths would reduce the limits on both charts.

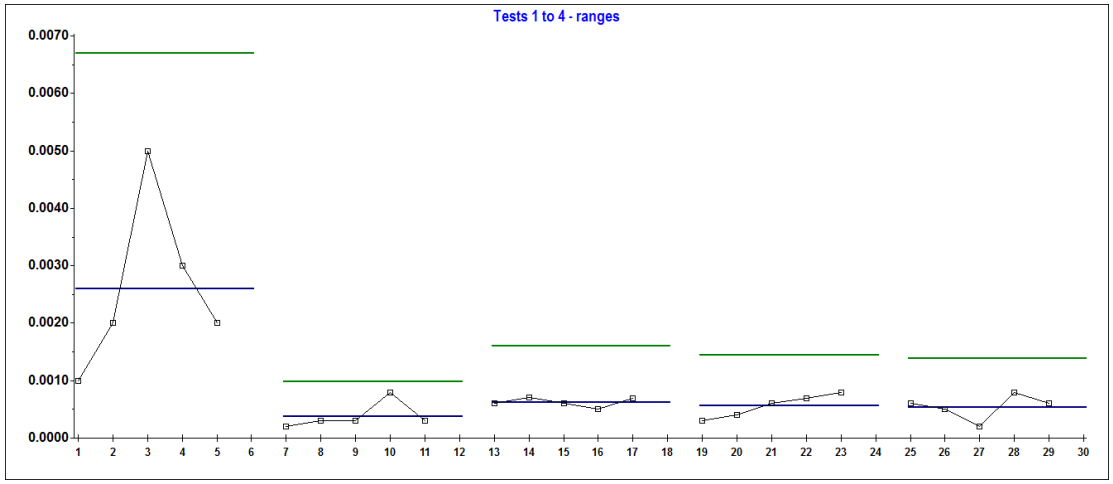
Example from a CMM

In the process of verifying a non-contact measuring machine (CMM), measurements were taken along a linear scale. The measurements were:

E_{UY} – length measurements in the Y axis
E_{UX} – length measurements in the X axis
E_{UXY} – length measurements in the X and Y axes
E_{UZ} – length measurements in the Z axis

Before proceeding with the usual uncertainty calculations, the data were fed into an SPC package (WinChart™) in order to check the stability of the process. The mean and range charts obtained are given below and really speak for themselves! – the process is not stable particularly for the E_{UXY} measurements (we would have expected each measurement type to exhibit the roughly the same behaviour for both the means and ranges!


Tests 1 to 4 - means
Euy
Eux
Euxy1
Euxy2
Euz
0.0030
0.0020
0.0010
0.0000
-0.0010
-0.0020
-0.0030
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30


Tests 1 to 4 - ranges
0.0070
0.0060
0.0050
0.0040
0.0030
0.0020
0.0010
0.0000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30

5.0 Capability

After checking the stability and control aspects of a measuring process, we need to ask the Important question: "Is the measuring process capable of doing the job we require of it?". Naturally, we impose a desired level of accuracy on any measurement, but can our measuring device meet that requirement. To help in the assessment of the capability of a measuring device, a number of indices have been devised. As we shall see, no single index is adequate to do a proper assessment as each looks at a particular aspect of the problem

5.1 The Capability Process (C_p) Index

The $_{Cp}$ index measures the dispersion or spread of the process relative to the desired accuracy. Basically, it is argued that the capability should be such that 3 standard deviations falls within the desired accuracy range. Thus we have,

$$C_p = \frac{\text{specified requirement}}{6s}$$

$$= \frac{\text{Upper tolerance - Lower tolerance}}{6s}$$

Figure 5.1 illustrates the situations the C_p index is designed to monitor.

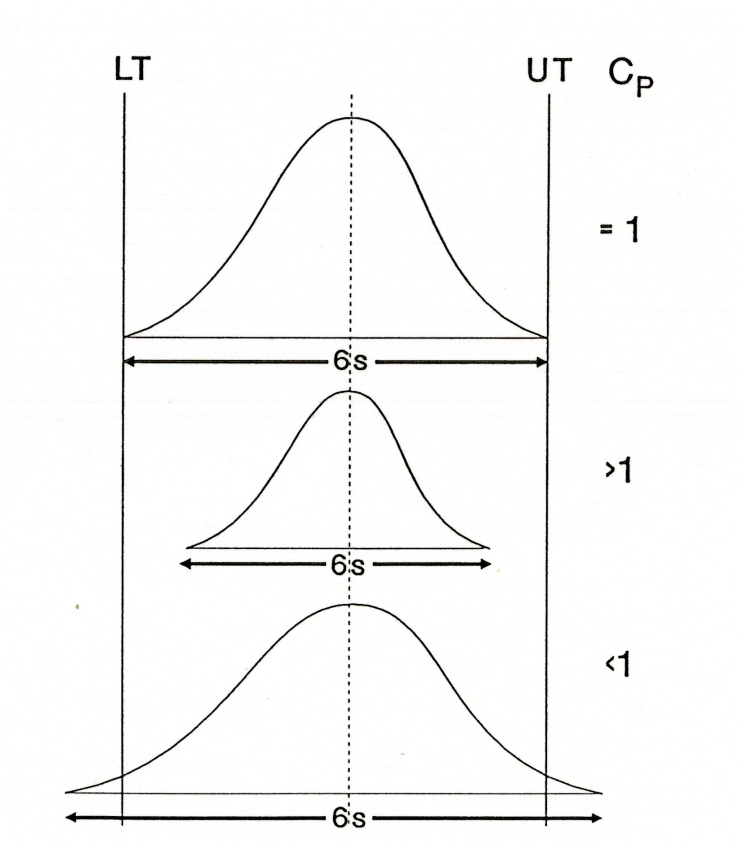


Figure 5.1

In metrology, the acceptability level of C_p Is naturally somewhat higher than what is commonly accepted for "ordinary" process control and is summarized by the following table.

$C_p > 10$	GOOD
$3 < C_p < 10$	ACCEPTABLE
$C_p < 3$	POOR

5.2 The C_{pk} Index

Whilst the C_p index considers whether the dispersion of the measurement is adequate, it does not take into account whether the mean of the measurements is "on target". The dangers of this are well illustrated in Figure 5.2, where the C_p index has a value greater than one but where clearly the situation is far from being satisfactory.

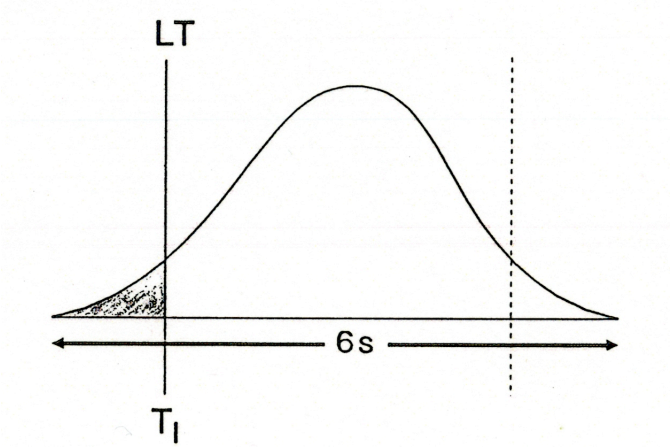


Figure 5.2

The C_{pk} index has been devised to take both these features into account. C_{pk} is defined to be the minimum of

(a) $\dfrac{\text{Upper tolerance limit} - \bar{x}}{3s}$

and

(b) $\dfrac{\bar{x} - \text{Lower tolerance limit}}{3s}$

The range of acceptable levels for the values of C_{pk} are the same as those for C_p. Now, applying this index to the situation illustrated in Figure 5.2 would give a value less than one, thus the C_{pk} index seems to be doing its job! (Note: the value of the C_{pk} index is always less than or equal to C_p.)

The calculation of the values of C_p and C_{pk} is illustrated in the following study of the capability of a 0-600mm vernier used to measure the width of a product (the data shown have been coded by subtracting 108 from each measurement). The upper tolerance is + 2mm and the lower tolerance is -1 mm.

Subgroup N•	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
x_1	0.10	0.14	0.20	0.10	0.28	0.14	0.06	0.06	0.10	0.20	0.10	0.18	0.18	0.08	0.19	0.24	0.24	0.14	0.14	0.14
x_2	0.18	0.08	0.05	0.14	0.08	0.16	0.10	0.17	0.10	0.10	0.02	0.16	0.18	0.08	0.30	0.14	0.18	0.10	0.10	0.12
x_3	0.14	0.14	0.24	0.14	0.24	0.06	0.24	0.18	0.14	0.10	0.06	0.08	0.17	0.10	0.10	0.10	0.17	0.10	0.17	0.04
x_4	0.16	0.20	0.14	0.14	0.10	0.04	0.12	0.12	0.10	0.10	0.08	0.20	0.14	0.24	0.04	0.16	0.16	0.17	0.11	0.20
x_5	0.14	0.14	0.12	0.13	0.16	0.04	0.08	0.22	0.06	0.10	0.18	0.08	0.18	0.21	0.24	0.21	0.07	0.09	0.17	0.16
$\bar{x}$	0.14	0.14	0.15	0.13	0.17	0.09	0.12	0.15	0.10	0.12	0.09	0.14	0.17	0.14	0.17	0.17	0.16	0.12	0.14	0.13
w	0.08	0.12	0.19	0.04	0.20	0.12	0.18	0.16	0.08	0.10	0.16.	0.12	0.04	0.16	0.26	0.14	0.17	0.08	0.07	0.16

Overall mean $\bar{\bar{x}} = 0.14$

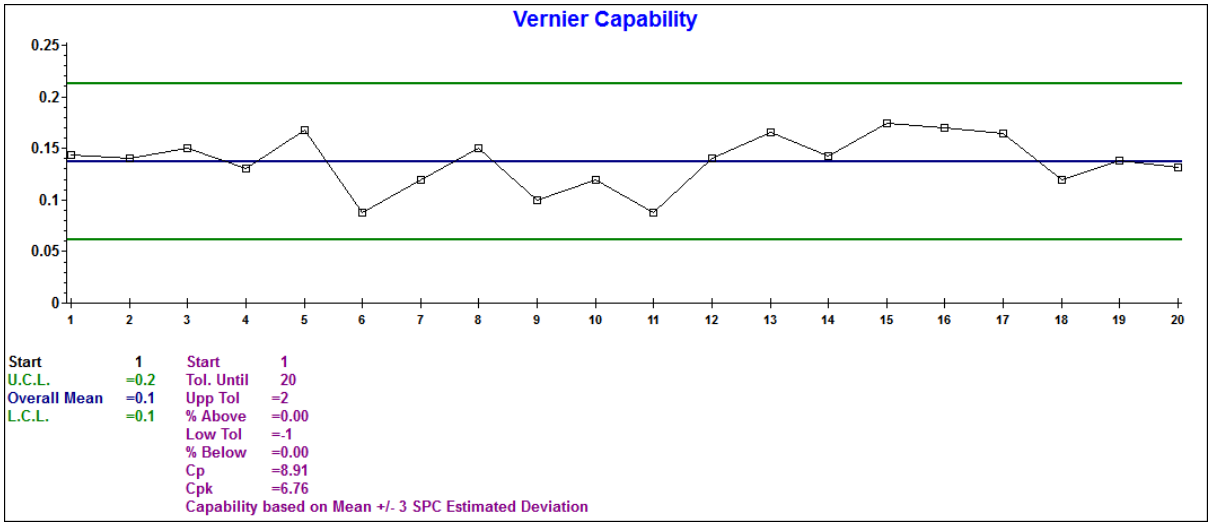
Mean range $\bar{w} = 0.13$

Hence the standard deviation s is estimated by $\bar{w}/d2$ (the value of d2 coming from the table of control chart constants). This gives the estimated value of the standard deviation as

$$s = \frac{0.13}{2.326} = 0.056$$

Thus,

$$C_p = \frac{\text{Upper tolerance - Lower tolerance}}{6s} = \frac{(+2) - (-1)}{6 \times 0.056} = 8.93$$


Vernier Capability
0.25
0.2
0.15
0.1
0.05
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Start 1
U.C.L. =0.2
Overall Mean =0.1
L.C.L. =0.1
Start 1
Tol. Until 20
Upp Tol =2
% Above =0.00
Low Tol =-1
% Below =0.00
Cp =8.91
Cpk =6.76
Capability based on Mean +/- 3 SPC Estimated Deviation