Plastics Topics – Quality management fundamentals

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1. Introduction

Quality management was one of the most discussed topics in manufacturing industry in the late 20th century. Many companies embarked on the pursuit of quality and for many the results were disappointing and they are still confused about what 'quality' really means and how they achieve it.

Many of these companies believed that implementing a formal quality system to ISO 9001 would deliver 'quality' and quality management still consists of filling out forms and final inspection. However, a Quality Management System to ISO 9001 does not necessarily improve quality. At many sites, the basics of quality have been missed and have there are many forms but little real management information or involvement.

This guidance document explores the essentials of cost-effective quality. It looks at quantifying the cost of quality to provide a driving force for change and the essentials of Statistical Process Control to provide a robust methodology to understand and control process variation.

"Of course we believe in quality - look at all the inspectors we employ."

2. First Steps

The first step in managing quality is to understand what the cost of quality is and where it comes from. This can be seen as a simple accounting exercise but it provides the essential driver for company-wide quality improvement rather than simple fire-fighting individual concerns. Companies are driven by the need to make profits and when the true cost of quality is revealed then management will inevitably take action.

An initial estimate of the overall cost of quality to a company can be achieved very rapidly from a good set of management accounts. It is simply a matter of identifying the relevant cost codes and running the report. The actions that must be taken afterwards are the real issue and are what counts.

The basic concept of Statistical Process Control SPC) was developed by Walter Shewhart and used extensively in World War II (billions of bullets must all fit millions of guns). It was refined by W. Edwards Deming and Joseph Juran and formed the basis of the Japanese industrial renaissance. SPC is prevention tool that is used to control the process and control of the product naturally follows – quality is therefore 'built in to the product'. Conventional inspection finds defects after they have been created – quality cannot be inspected into a product; inspection simply sorts out and rejects bad product.

SPC is based on some complex statistics and there are many excellent references on the statistics[1,2,3]. This guidance document takes a very simple but still statistically sound, approach to demystify SPC and show how it can be practically used in plastics processing to control processes, prevent defects and improve productivity.

Quality costs[4]

An essential driver in improving quality is finding out what and where quality costs a company money. In most books the terminology used is 'the cost of quality' or 'quality costs' and we will continue to use this for the sake of conformance with the existing literature. The problem with these terms is that they immediately imply that quality is a discretionary cost and that if you stop spending money on quality that your costs will decrease and profits increase. This also creates the impression that quality is a 'burden' on the company. Nothing could be further from the truth - if you stop spending money on quality then profits will decrease and eventually the company will cease to exist.

In this document, we will look only at the size of the costs and the opportunities for improving the overall financial performance and productivity of a company.

- [1] Juran J.M and Defeo, J.A. 2016. 'Juran's Quality Handbook' (7th Edition), McGraw Hill.
- [2] Grant, R.S. and Leavenworth, E.L. 1996. 'Statistical Quality Control'. McGraw Hill.
- [3] Price, F. 1986. 'Right First Time: Using Quality Control for Profit'. Routledge. A great read with everything you need to know and very readable.
- [4] Kent, R.J. 2016. 'Quality Management in Plastics Processing' (First Edition), Elsevier.

The magnitude of the costs

For the majority of plastics processing sites, the cost of poor quality is in the region of 20% of sales. This comes mainly from failure costs, i.e. where the product does not meet the requirements. This can be either an internal cost (if the product does not reach the external customer) or an external cost (if the product is dispatched to the external customer). Failure costs generally dwarf the other quality costs such as appraisal costs, i.e. inspection costs, and prevention costs, i.e. what we do to stop failure happening in the first place.

The typical 'real' costs are shown below and these costs will usually be significantly higher than the profit margin for a plastics processing company. Despite this, few sites are able to accurately (or even inaccurately) quantify and allocate their real quality costs. A basic understanding of the quality costs at any site will provide a real driving force for quality improvement. The exact costs for each site will depend on the operations but the 'real' costs will be approximately correct for the majority of sites.

Actual		Ideal	
Prevention	5%	Prevention	25%
Appraisal	25%	Appraisal	35%
Failure	70%	Failure	40%
Total cost of quality ≈ 20% of sales.		Total cost of quality ≈ 10% of sales.	

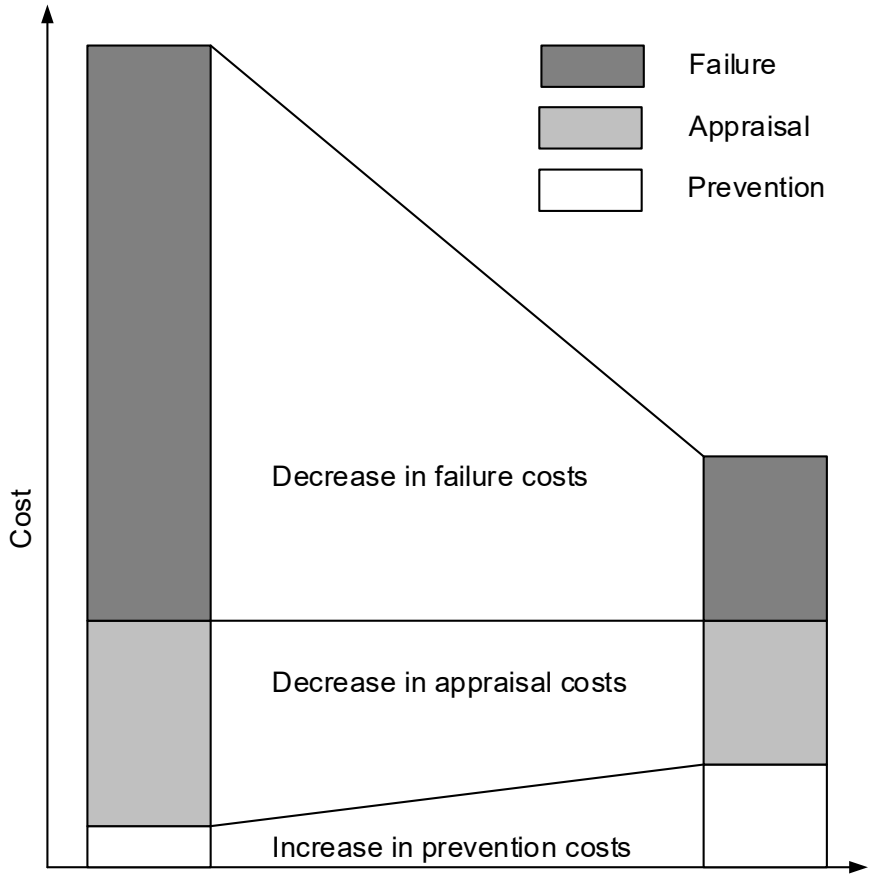


Figure 1: The actual and ideal divisions of the cost of quality

What is in the cost of quality?

The components of prevention, appraisal and failure (internal and external) are shown in Figure 1 to allow a review of internal cost codes to generate a first-pass cost of quality for a company:

Prevention costs	Appraisal costs	Failure costs
• Pre-contract meetings. • Contract review. • Design review. • Realistic design tolerances. • Quality plans and planning. • Supplier selection and approval. • Process design. • Planning and scheduling. • Planned maintenance. • Housekeeping. • Packaging. • Statistical process control. • Special investigations into failure costs. • Quality reports. • Quality improvement. • Quality system auditing (internal and external). • Quality system approval costs. • Training personnel in quality.	• Sales target monitoring. • Customer satisfaction surveys. • Supplier monitoring. • Inwards goods inspection. • Design verification. • Stock control. • In-process inspection. • Final inspection. • Storage facilities for 'hold' products. • Purchase of test equipment, gauges and measuring devices. • Control and calibration of test equipment, gauges and measuring devices. • General quality control overheads. • Inspectors' wages. • Training assessment. • Personnel appraisal.	**Internal** • Scrap. • Labour overhead. • Rework. • Re-inspection. • Sorting of product. • Extra operations. • Selective production and assembly. • Downtime. • Scrap material. • Losses on sale of substandard items. • Late or replacement deliveries. **External** • Customer complaint servicing. • Customer returns. • Credit notes. • Discounted sales. • After sales service (under guarantee or warranty). • Fault investigations and rectification. • Interest on unpaid invoices. • Product recall costs (transport, paperwork etc.). • Litigation costs. • Poor press/PR. • Lost sales and customer accounts through bad reputation and delays. • Lost sales opportunities. Internal failure costs: £ External failure costs: £
Prevention costs for previous 12 months: £	Appraisal costs for previous 12 months: £	Total failure costs for previous 12 months: £

Table 1: The elements of a cost of quality calculation

The magnitude of the savings

The possible savings from good quality management are in the region of 50% of the current quality costs for most plastics processing sites. Savings of this magnitude are significantly higher than the profit margin for most plastics processors.

These savings can be delivered virtually irrespective of the industry sector or process used. The process used makes little difference in the potential savings - it is management that makes the difference.

These savings are possible by changing resource allocation from dealing with the product after it has failed to preventing the product failing in the first place. Increasing resources in prevention may cost more money initially but greatly reduces later failure costs.

The majority of the savings can be delivered through a balanced combination of no-cost, low-cost and investment (maintenance or capital) actions. The average payback for most investments in quality management is less than 12 months. This is true even when the payback is calculated using the costs for internal management efforts.

This type of payback makes investment in quality management extremely attractive from a purely financial point of view. Not many capital investment projects achieve a payback of less than 1 year and continue to deliver the benefits virtually indefinitely. Yet many sites fail to carry out attractive quality improvement projects because they have a faulty understanding of how quality can be improved. They continue to spend money on appraisal costs and accept the failure costs because these are regarded as inevitable. Capital investment proposals are still primarily presented based on direct labour reductions and rarely put forward based on reducing quality costs.

In many cases, a site's quality costs are almost a discretionary cost, i.e. the site chooses to pay the cost of quality because it chooses not to do anything about it. Reducing the discretionary cost of quality at any site is directly geared to the profit of the site.

Any cost saving due to quality management translates directly to the bottom line and is shown as a direct increase in profit. Work in quality management is as valuable as work to reduce direct labour and in many cases the savings are more easily achieved because previous work to reduce direct labour has already removed the easy wins.

Reducing the cost of quality is extremely profitable. When the cost of quality is reduced, it adds directly to the bottom line - something that increasing sales does not do. If the quality costs are 20% of the turnover and the profit margin is 5% then reducing quality costs by 25% (equivalent to 5% of the turnover) is the same as adding 100% to the profit. To achieve the same result through increased sales would require doubling the sales - not an easy task. What would your site do to gain new business that increased turnover and profit by 100% if you knew that:

- Your competitors couldn't stop you getting the business.
- The business was effectively guaranteed.
- The business required only internal effort.
- The business was low-risk and had a payback of less than 12 months.
- The business would continue into the future and probably increase in value.

Most sites are enthusiastic about gaining new business through increased sales. Yet when shown the opportunity to reduce quality costs and achieve the same results at the profit line, the same sites react with huge indifference. The saying is that 'turnover is vanity, profit is sanity' and the unfortunately many sites still prefer the vanity of increased turnover.

Statistical Process Control (SPC)[5]

Every process (and the output product) varies. Variability is a fact of life and SPC both acknowledges this and provides the tools to deal with it.

Although it is Statistical Process Control, the statistics are minimal during operation and all the statistical definitions you need this know are shown in Figure 2:

[5] Kent, R.J. 2016. 'Quality Management in Plastics Processing' (First Edition), Elsevier.

X A measurement value

$\overline{X}$ X BAR - The average of a number of measurements

$\overline{\overline{X}}$ X DOUBLE BAR - The average of a number of averages.

R RANGE - The difference between the largest and smallest measurements in a group of measurements.

$\overline{R}$ R BAR - The average of a number of ranges.

σ SIGMA - The standard deviation - a measurement of how wide a distribution is.

Population: All the parts in a batch or run.

Sample: A selection from the population.

Figure 2: All the statistical definitions that you need to know

You are now a statistical expert because you know more about statistics then most people!

The capability study

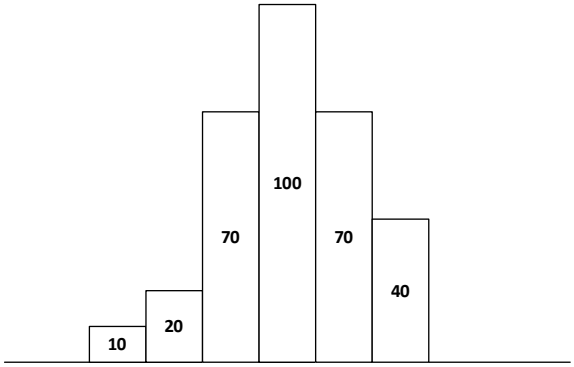
A capability study is simply a method of assessing if it is possible for a given machine or process to produce to a given specification.

If we take a sample of parts from a machine (all produced at the same time) and measured a single property such as a dimension then we would expect a variation in the measurements. These results can be plotted on a bar chart (or histogram) and joined up to form a distribution of the results.

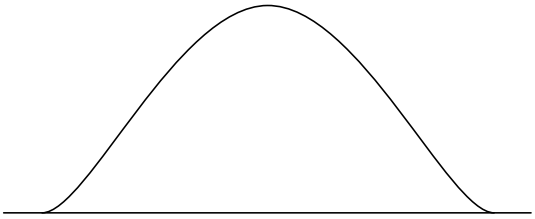
If we measured enough points to get the results for the whole population the in most cases we would end up with a smooth curve and it would probably look like the bell curve or normal distribution. The good thing about the normal distribution is it is found in many natural and industrial populations and that statisticians have been working with this for many years and know a lot about it. The steps:

Select 50 samples from a continuous run of product.

Measure the desired feature and plot results in a histogram using 6 bars:



If the distribution is approximately a normal distribution, then proceed.



Note: If the distribution is not a normal distribution, then other techniques may be needed.

Calculate the mean ($\overline{X}$) and the standard deviation (σ) for the 50 results using a spreadsheet.

Estimate the process variability (relative to the specified tolerances) from the formula:

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

where:

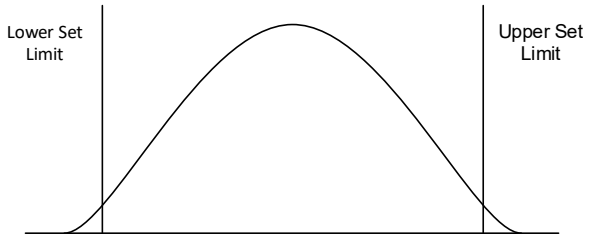
USL = Upper Set Limit or Upper Tolerance.

LSL = Lower Set Limit or Lower Tolerance.

C_p is a measure of the 'process spread'. If C_p is < 1.00 then it will not be possible for the process to produce parts within tolerance. When C_p is > 1.33 the process is said to be 'capable'.

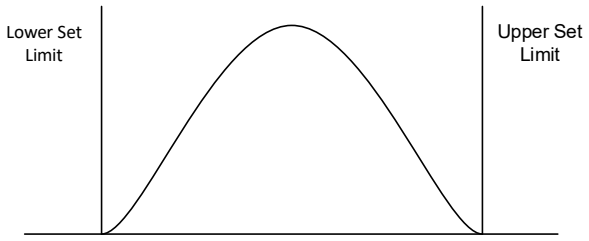
C_p is less than 1.00

The process is centred on the tolerances but it will never be possible to produce all the parts inside the tolerance.



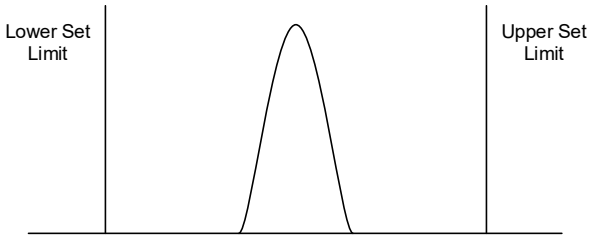
C_p is equal to 1.00

It will be possible to produce 99.73% of the parts inside the tolerances but only if the process is exactly centred on the tolerance band and does not vary.



C_p is greater than 1.33

The process spread is less than the tolerances. It will be possible to produce all the parts inside the tolerances even with process variations.



Cp only describes the spread; it does not describe the location and even with a small spread (Cp >1.33) it is possible to produce out of tolerance parts. We need to be able to describe the location of the curve, this is done as follows:

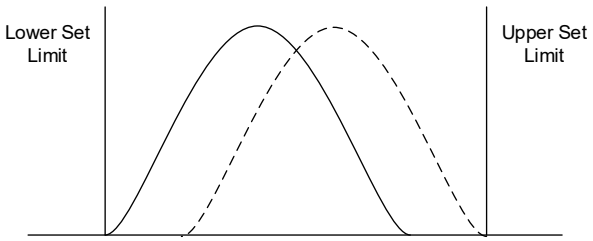
Calculate Z_{UPPER} and Z_{LOWER} from the formulae below and find the smaller of the two:

Z_{min} is the smaller of $Z_{UPPER} = \frac{USL - \overline{X}}{\sigma}$ and $Z_{LOWER} = \frac{\overline{X} - LSL}{\sigma}$ and $C_{pk} = \frac{Z_{min}}{3}$,

As with C_p, if C_{pk} is less than 1.00 then it will not be possible for the process to produce parts within tolerance. When C_{pk} is > 1.33 the process is said to be 'capable'.

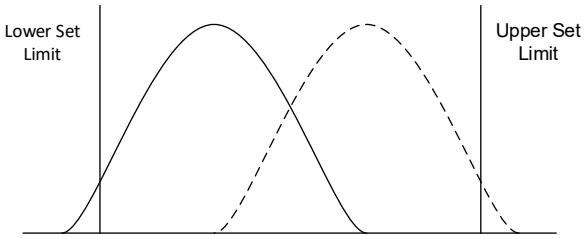
C_{pk} is less than 1.00

The process location is outside the tolerances. It will not be possible to produce all the parts inside the tolerances.



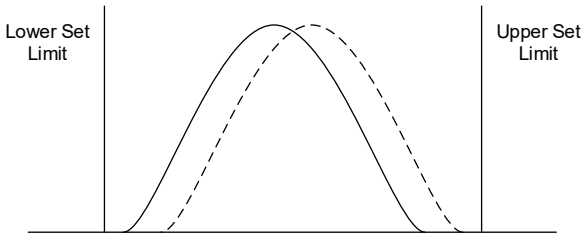
C_{pk} is equal to 1.00

The process location is inside the tolerances but close to the limits. It will just be possible to produce all the parts inside the tolerances.



C_{pk} is greater than 1.33

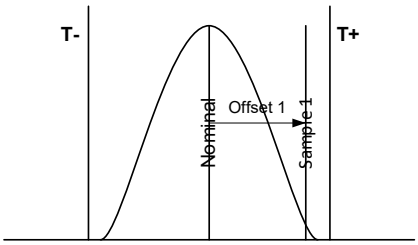
The process location is well inside the tolerances. It will be easily possible to produce all the parts inside the tolerances.



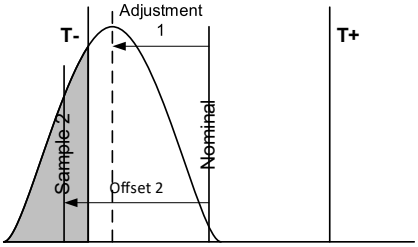
It is possible to use the values for Z_{UPPER} and Z_{LOWER} with P_z tables to calculate the proportion of the output that will be beyond the specification limits.

Process setting

The operator selects one sample (which happens to be at the top end of the distribution) and finds that it is 'high'. The process is set with this single high reading despite the fact that the process is actually totally OK.



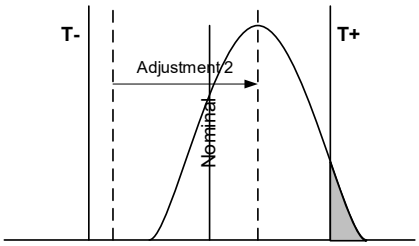
The process is adjusted downwards (Adjustment 1) by the same amount that it was running high – pushing the process so that it produces parts outside specification. The process is again measured and found to be running low.



The process is again adjusted (Adjustment 2) and this time overshoots so that it is running high and parts are again produced outside of specification.

The cycle continues and see-saws in and out of control.

This happens day after day in industry.



Even worse (perhaps) is when the operator selects a sample that shows the process to be OK when it is mostly outside the tolerance limits - the process is then operated with out-of-tolerance parts being produced while the operator thinks that everything is OK.

To set a process you should never rely in a single sample result. Always make at least 5 measurement and set the process on the basis of the average of the 5 measurements.

The control chart

The capability study tells us if we can make the product OK but the control chart tells us if we are making it OK.

There are two distinct types of causes for variation in processes and they need to be separated to allow the process to be managed and improved. The two types of causes are:

Common causes – these are variations in the process that are due to natural random causes. They are predictable, characteristic of the process and cannot be totally removed or corrected. SPC accepts the presence of common causes and a process is considered to be 'in control' if the only variation is from common causes. If a process is 'in-control' then the performance of the process can be predicted and SPC tells you to do nothing with to the process!

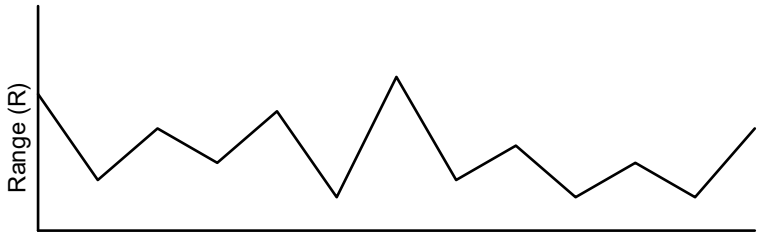
Special causes – these are the significant and identifiable causes or events which can lead to the production of products that do not meet the specification. SPC looks for non-random patterns that indicate the presence of special causes and then provides the tools to identify and rectify the special cause.

In this guidance document we will focus on variables (things we can put a number on such as length or weight) but the same type of process can be used for attributes (things that we cannot put a number on such a surface defects or marks).

The range chart

Using a running and stable process take 5 samples from the process each hour. Record the average ($\overline{X}$) and the range (R – the difference between the highest and lowest measurements) for the set of 5 samples. Continue until 25 sets of data are available.

Plot the results for the range (R) on a preliminary Control Chart as below:



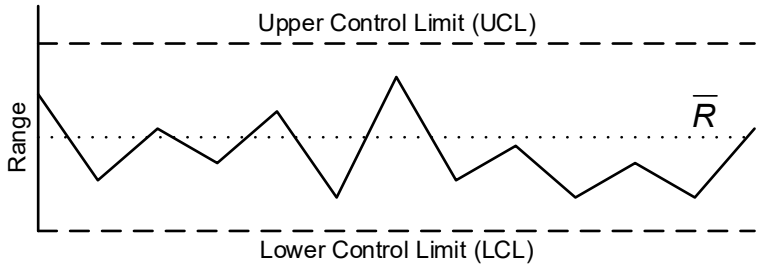
Calculating the control limits for R:

Find the average of the 25 values for R. This is $\overline{R}$ and $\overline{R} = \frac{\text{Sum of all R values}}{25}$.

For a sample size of 5 the control limits are given by

- Lower Control Limit for R: $LCL_R = 0$
- Upper Control Limit for R: $UCL_R = 2.11 \times \overline{R}$

Plot the average for the range ($\overline{R}$) and the Upper and Lower Control Limits (UCL_R and LCL_R) on the Control Chart:

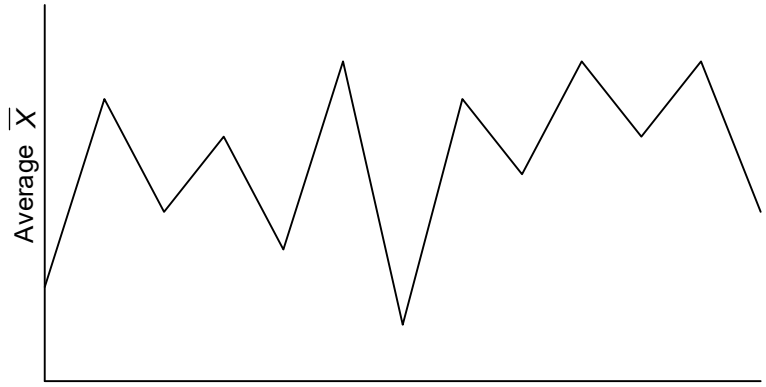


Interpret the Range Control Chart for control (see below).

The average chart

Using a running and stable process take 5 samples from the process each hour. Record the average ($\overline{X}$) and the range (R – the difference between the highest and lowest measurements) for the set of 5 samples. Continue until 25 sets of data are available.

Plot the results for the average ($\overline{X}$) on a preliminary Control Chart as below:



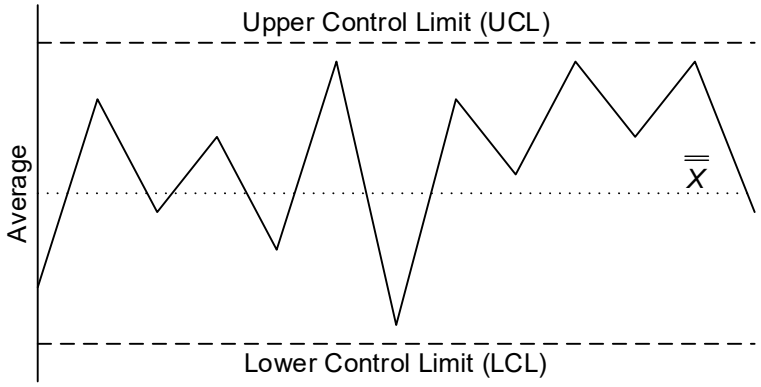
Calculating the control limits for $\overline{X}$:

Find the average of the 25 values for $\overline{X}$. This is $\bar{\bar{X}}$ and $\bar{\bar{X}} = \frac{\text{Sum of } \overline{X} \text{ values}}{25}$

For a sample size of 5 the control limits are given by

- Lower Control Limit for $\overline{X}$: $LCL_{\overline{X}} = \bar{\bar{X}} - 0.58 \times \overline{R}$
- Upper Control Limit for $\overline{X}$: $UCL_{\overline{X}} = \bar{\bar{x}} + 0.58 \times \overline{R}$

Plot the average of the averages ($\bar{\bar{X}}$) and the Upper and Lower Control Limits ($LCL_{\overline{X}}$and $UCL_{\overline{X}}$) on the Control Chart:



Interpret the Average Control Chart for control (see below).

Using and analysing control charts

Use the previously created range and average control charts with the Average and the Upper and Lower Control limits marked on them.

Measure 5 samples every hour and calculate:

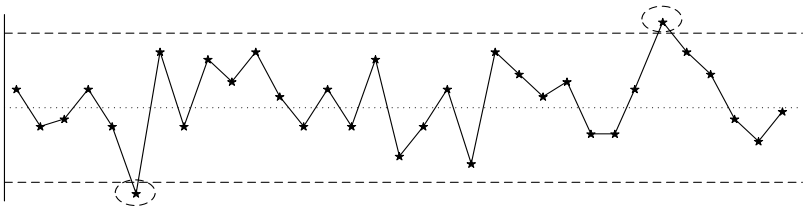
- The average of the 5 measurements ($\overline{X}$).
- The range of the 5 measurements (R).

Plot $\overline{X}$ and R on the relevant Control Chart during the production run.

Interpret the Range Control Chart first.

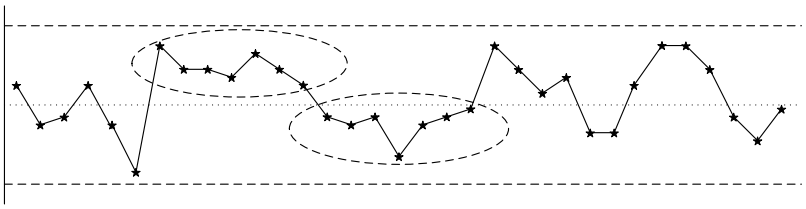
Look for any of the following patterns:

- No points outside the control limits (upper of lower):



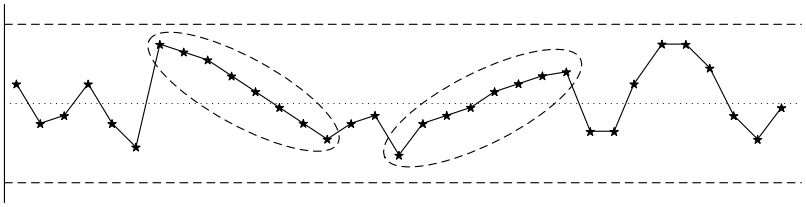
Points outside the control limits show 'special events' have occurred and 'out-of-control' parts were made.

- No run of 7 consecutive points above or below the average line:



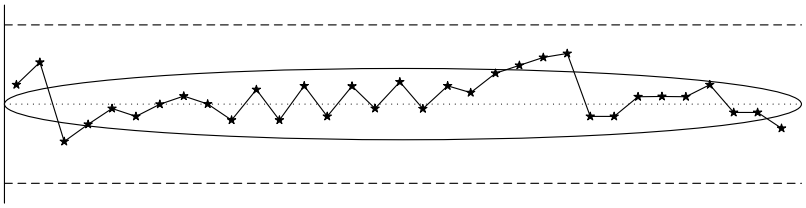
There is a step change in the process. Check for new materials or similar changes.

- No run of 7 consecutive points upward or downward:



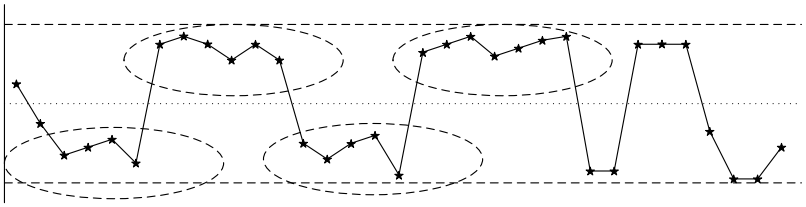
The process is drifting upwards or downwards. Check for tool wear or similar gradual changes

- No pattern with 2/3 of the points in the middle 1/3 of the control limits:



The process is too consistent, check and recalculate the Control Limits.

- No pattern with 2/3 of the points in the outer 2/3 of the control limits



The process may have internal variations. Are two tools being used and has the output been mixed up?

If any of these patterns are present then the process is out of control for the range. Investigate for special causes and correct as required.

If the Range Control Chart is in order, then interpret the Average Control Chart:

Look for the same patterns in the Average Control Chart as in the Range Control Chart:

- No points outside the control limits (upper of lower)
- No run of 7 consecutive points above or below the average line
- No run of 7 consecutive points upward or downward
- No pattern with 2/3 of the points in the middle 1/3 of the control limits
- No pattern with 2/3 of the points in the outer 2/3 of the control limits

If any of the patterns is present then the process is out of control for the average. Investigate for special causes and correct as required.

Important Points for using Control Charts

- Operators should carry out the measurements and record them on the chart themselves – this is not to be done by 'Quality Control', it is an operator task.
- Operators should join the recorded and calculated points together with a straight line to the previous result.
- Operators should always initial and date the Control Chart when they make the measurements.
- Operators should always record significant events (materials batch changes, operator changes, colour changes etc) on the Control Chart – it makes finding the special causes easier to find and rectify.
- Control Charts are working documents, not works of art.
- Unless the Control Chart indicates one of the above patterns then the process should never be adjusted by the operator. Parts are being produced in tolerance and the process is in control – there is no need for adjustment. To drive this home, make adjusting the machine without a Control Chart warning a disciplinary offence.
- Do not be in a rush to adjust the machine – always study the process carefully before making any adjustments to the machine.
- Control Charts provide a 'common language' for operators, managers and reporting. They are the glue that holds a factory together.
- Control Charts can be used to detect 'special causes' these can be fixed or eliminated by local action.
- The detection and elimination of 'common causes' (the reason for the Upper and Lower Control Limits) is generally much more difficult. Eliminating 'common causes' generally requires management action and possibly even investment in the process.

What about 6–sigma?

This guidance document is focused on demystifying the use of statistics to improve quality. 6-sigma uses many of the statistical tools (rebranded for a new generation) and extends these into a more general management process (DMAIC). Despite this, the fundamental statics of capability studies and process control charts are still valid and can improve productivity in plastics processing by reducing variation and improving output quality.

- The Chartered Quality Institute (https://www.quality.org) has good resources on all aspects of quality management.

3. Case Studies

Quality costs

Some years ago, we decided to collect the Cost of Quality numbers at our injection moulding site. We were fortunate in having not only a good management accountant but also a good set of management accounts. The accountant and I simply went through the cost codes for each department and allocated these into the PAF categories for each department. The accountant then ran the report from the system and suddenly, as if by magic, we had a complete COQ for the site.

The reaction from the accountant was one of horror as he realised the total COQ was nearly 30% of our costs.

His simple questions were:

- Why weren't we taught to look for this in the accounting courses?
- Why did it take an engineer to show this to me in my accounts?

After the numbers were complete and the magnitude of the cost was revealed, there was no longer any problem with investment approval for quality management and the 'cost of quality' report became a regular management report at Board level. The accounts function were now on board with the

process of reducing the COQ at the site. They knew the numbers and they worked with them to reduce the overall cost of quality.

Even rough figures will show that the cost of quality is a significant proportion of turnover and far higher than the profits.

SPC – Extrusion

The capability study or 'Can we make it OK?'

An extrusion site was producing extruded sheet for later thermoforming into food trays. The site regranulators were stacked with 'reject' product from the extruders on the basis of thickness variations.

A rapid process capability study (see Section 0) was carried out on 50 consecutive historical data points extracted from the QC records for sheet thickness. These data were taken over both the day and the night shifts.

These data were used to produce the capability study histogram shown on the lower right. This does not look exactly like a normal distribution but this is explained when it is considered that the operators are making manual measurements with micrometers. The operators are reluctant to measure in '5s' and prefer to measure in '10s'. This is easy to do with a manual micrometer and the operators will tend to 'fudge' the results. This is normal human behaviour and is not a criticism of the operators. This behaviour is shown quite clearly in the histogram.

The specification for the product is 575 µm ± 6% (± 34.5 µm). This gives:

- USL = 609.5 µm (Upper Set Limit or Upper Acceptable Tolerance).
- LSL = 540.5 µm (Lower Set Limit or Lower Acceptable Tolerance).

The nominal thickness, the USL and the LSL are all marked on the capability study histogram.

The distribution was considered to be approximately a normal distribution (subject to the operator adjustment) for the purpose of analysis.

The results of the capability study showed that the average ($\overline{X}$) of the results was 574.02 µm and the standard deviation (σ) of the results was 11.96 µm.

Process spread

The process spread (relative to the specified tolerances) is described by the process capability, C_p (see Section 0). For the process studied, $C_p = 0.96$.

When C_p is < 1.00 then the normal distribution width is greater than the tolerance band width. This means that defects will always be produced at the top or bottom of the tolerance band and it will not be possible for the process to produce parts within tolerance.

Out-of-tolerance products will be produced even if the process is exactly centred and does not vary.

Process location

The process location is described by the process capability index C_{pk} (see Section 0). For the process studied, $C_{pk} = 0.93$.

When C_{pk} is < 1.00, as in this case, then the normal distribution is not centrally located and it will not be possible for the process to produce parts within tolerance.

The process is located such that out-of-tolerance products are produced.

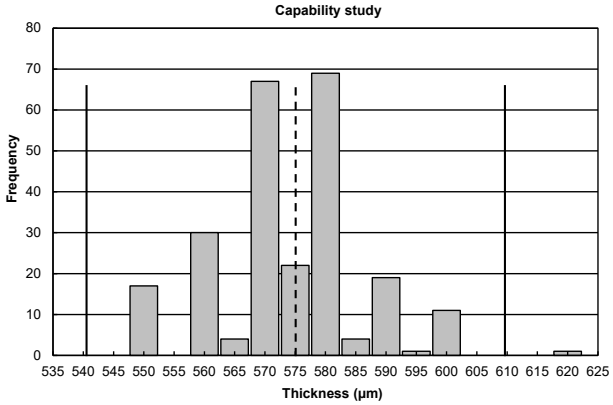


Figure 3: An initial process capability study for sheet extrusion

This simple data analysis and treatment shows that the process is not capable of reliably producing product within specification, i.e. nonconformities will always be produced.

In cases such as this, where the process is not capable, then the process:

- Should be examined for improvement to reduce the variation.

AND/OR

- The tolerances adjusted to more realistic levels, in consultation with the customer, to increase the process capability.

If this is not done then the process will continue to produce excessive out-of-tolerance products and reject material will continue to be sent for regranulation.

The control chart or 'Are we making it OK?

The QC records were further analysed to produce average and range ($\overline{\mathrm{X}}$ and R)charts for the running process. The 5 values measured at each inspection were taken as the five samples for SPC by variables (see Section 0).

The control limits were calculated using standard SPC formulae and are:

Range chart:

UCL_R = 24.9 µm.

$\overline{\mathrm{R}}$ = 11.65 µm.

LCL_R = 0 µm.

Average chart:

$\mathrm{UCL}_{\overline{\mathrm{X}}}$ = 567.27 µm.

$\overline{\overline{\mathrm{X}}}$ = 574.02 µm.

$\mathrm{LCL}_{\overline{\mathrm{X}}}$ = 580.78 µm.

The control limits and process data are shown below for the range (left) and the average (right):

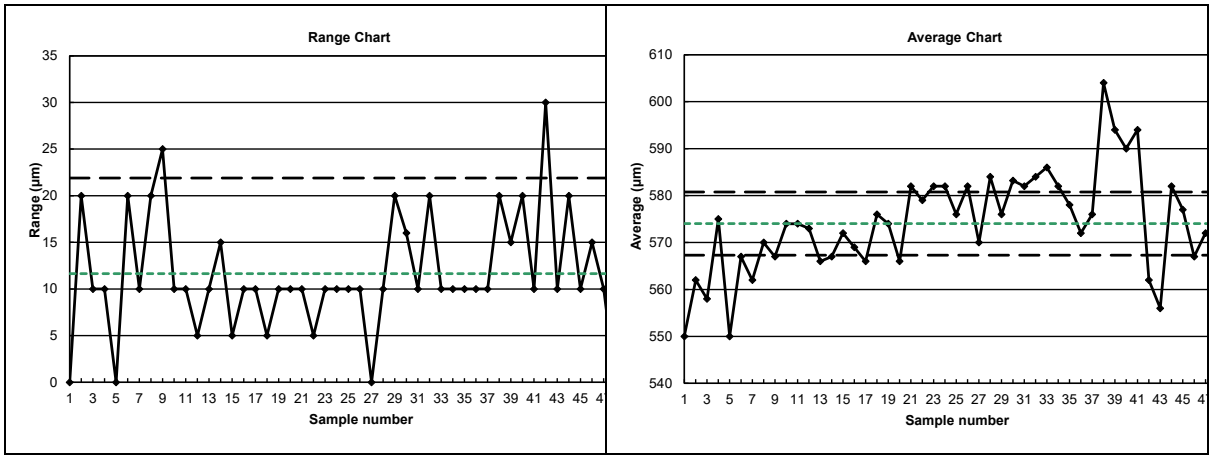


Figure 4: Range and average charts for sheet extrusion

The range chart shows that the range chart was broadly 'in control' for the whole period with the exception of two short periods at Samples 9 and 42. The rapid changes in the later section of the range chart (37 to 50) may indicate that more than one person was making the measurements or 'tampering' with the machine when it should not have been adjusted. The resolution of the measuring equipment for this case is also suspect due to the operator tendency to measure in 10s and not in 5s.

The average chart shows that the process was out of control almost all of the time. This is thought to be due to the operators 'hunting' for a stable process to meet a specification that simply could not be met. This behaviour explains the excessive rejects and the excessive use of the regranulators in the extrusion process.

This type of QC data is often available but it is rarely fully utilised. The simple analysis prompted a review and improvement of the complete process and a subsequent reduction in the scrap product being produced.

SPC – Injection moulding

There are many high-technology methods for quality control in injection moulding, e.g., cavity pressure measurement, but many processors do not have the time, money or staff to invest in and operate these tools. A typical injection moulding has a multiple key dimensions and using SPC process control on all of these can be very time consuming.

One approach is to use a single surrogate measurement for all of the process parameters. The most common surrogate measurement is the product weight. If the tooling has been dimensionally validated and the process has been set correctly before series production then the product weight will be a measure of continued control. It is reasonably simple to set up and use a variables control chart based on product weight and then to use the product weight for process control.

An in-house moulder had a 'problem' tool with an average scrap rate in the region of 25%. The mould was never capable of running for more than 2 hours without having to be seen by the setters and the output was always inconsistent and of poor quality.

They spent some time on the basics:

- Finding out the best settings (using capability studies and a set of properly designed experiments).
- Recording the settings on the setting sheet.
- Training the operators in SPC and 'when to do nothing'.
- Establishing the SPC limits and checking protocols.

The simple control was to measure the weight of the output and use this for a control chart. Operators were warned that tampering with the controls whilst the chart showed the process to be in control was a disciplinary offence.

The product ran for around 56 hours with absolutely everything running fine and no setting changes by anybody. This was regarded as a true miracle by all concerned but we knew it couldn't last.

Finally, the control chart indicated ‘out-of-control’ and everybody panicked. The settings, the material, the control charts were all checked. They were just about to give up and modify the settings when the Senior Tool Setter found the problem. The cleaner had moved a rubbish bin at the back of the machine and accidentally kinked a cooling water hose. This restricted the flow and the cooling of the mould. The hose was straightened the hose and after 20 minutes the chart indicated that the process was ‘in control’ once more and the run continued.

Note: If using product weight as a surrogate measurement then the control limits may need to be reduced to be sure of reliably identifying process changes, i.e. try using $\overline{\overline{X}} \pm 2\sigma$ instead of $\overline{\overline{X}} \pm 3\sigma$ to set the control limits for the variables chart.