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The INSTITUTE *for* IMPROVEMENT *in* QUALITY *and* PRODUCTIVITY

Waterloo, Ontario, Canada N2L 3G1
(519) 888-4593

QS-9000 and Process Capability Indices

S.H. Steiner, B. Abraham and R.J. MacKay
University of Waterloo

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Stefan Steiner, Bovas Abraham and Jock MacKay
Institute for Improvement of Quality and Productivity
Department of Statistics and Actuarial Science
University of Waterloo
Waterloo, Ontario N2L 3G1

1. Introduction

QS-9000 is an automotive industry quality standard developed by the Chrysler, Ford and General Motors Supplier Quality Requirements Task Force. QS-9000 represents an extension of the well known worldwide standard ISO-9000. The QS-9000 standard is outlined in the manual "Quality Systems Requirements," with further information given in the reference manuals: "Statistics Process Control", "Advanced Product Quality Planning and Control," "Measurement Systems Analysis", and "Production Part Approval Process," all published by the Automotive Industry Action Group (1995). The QS-9000 standard emphasizes prevention, continuous improvement and provides both a broader basis and more details than the ISO-9000 standard.

QS-9000 provides many prescriptions designed to promote quality improvement and consistency in manufacturing. In particular, parts of the QS-9000 standard discuss minimum process capability requirements. A process capability index is a numerical summary that compares the behavior of a product or process characteristic to engineering specifications. These measures are also often called capability or performance indices or ratios; we use capability index as the generic term. A capability index relates the voice of the customer (specification limits) to the voice of the process. A large value of the index indicates that the current process is capable of producing parts that, in all likelihood, will meet or exceed the customer's requirements. A capability index is convenient because it reduces complex information about the process to a single number.

Capability indices have several applications. The use of the indices is driven by monitoring requirements specified by customers. Many customers ask their suppliers to record capability indices for all special product characteristics on a regular basis. The indices are used to communicate how well the process has performed. For stable or predictable processes, it is assumed that these indices also indicate expected future performance. In addition, the supplier can compare capability indices for different characteristics to establish priorities for improvement activity. Finally, the effect of a process change can be assessed by comparing capability indices calculated before and after the change. In summary, the use of capability indices is widespread and mandated by QS-9000.

The QS-9000 standard presents process capability requirements for variables data in terms of the indices P_p, P_{pk} and C_{pk}. The following three excerpts from the QS-9000 reference manuals illustrate the requirements. The process capability requirements given in Section 4.9.3. of the manual "Quality Systems Requirements" state, in part:

> "Ongoing process performance requirements are defined by the customer. If no such requirements have been established, the following default values apply:
>
> - For stable processes and normally distributed data, a C_{pk} value ≥ 1.33 should be achieved.
> - For chronically unstable processes with output meeting specification and a predictable pattern, a P_{pk} value ≥ 1.67 should be achieved."

In the Advanced Product Quality Planning (APQP) manual, the Ford Powertrain specific requirements for dynamic control plans (DCP, Appendix G) say, in part:

> "All processes must produce all characteristics to specification on a production basis. ... Significant Characteristics (SCs) must be in a state of statistical control with $P_{pk} \geq 1.67$ and $C_{pk} \geq 1.33$."

Within the Production Part Approval Process (PPAP) manual, the requirements that relate to process capability are given as follows:

"Calculate the P_{pk} index and take the following actions:

For Processes that Appear Stable

Results	Interpretation
P_p and $P_{pk} > 1.67$	The process probably meets customer requirements. After approval, begin production and follow the Approved Control plan.
$1.33 \leq P_{pk} \leq 1.67$	The process may not meet customer requirements. After part approval, begin production with additional attention to the characteristic until an ongoing $C_{pk} \geq 1.33$ is achieved.
$P_{pk} < 1.33$	The process is substandard for meeting customer requirements. Process improvements must be given high priority and documented in a corrective action plan. Increased inspection or testing is normally required until an ongoing C_{pk} of 1.33 is demonstrated. A revised control plan for these interim actions must be reviewed with and approved by the customer.

[Processes that appear unstable at the time PPAP approval is sought require special attention] ... until ongoing stability and an C_{pk} of 1.33 is demonstrated."

Due to the significance given to process capability, it is important that these requirements and the different capability indices are clearly understood. As shown by the excerpts, decisions about part acceptance and the meeting of ongoing customer requirements is based on the value of a capability index. However, there is currently much confusion about the different capability indices, their interpretation, and the mandated actions their interpretation lead to. The QS-9000 requirements use three different capability indices P_p, P_{pk} and C_{pk}, and contain unclear definitions of the conditions under which each is appropriate.

The goal of this article is to discuss the various capability indices and their interpretation in the context of the QS-9000 standard. In the next section, the various indices are defined and contrasted. It is shown that, from process information perspective, the index P_{pk} is always preferable. The third section discusses important issues associated with the calculation and interpretation of capability indices. It explains the roles of the data collection scheme, which is only briefly discussed in the standard (Ongoing Process Capability entry in the Glossary of the QS-9000 manual), and of process stability. The fourth section provides guidelines for a rewrite of Section 4.9.3 of the QS-9000 manual that would simplify and clarify the current requirements concerning process capability.

2. Definition of the Capability Indices

A capability index relates the engineering specification (determined by the customer) to observed behaviour of the process. The capability of a process is defined as the ratio of the distance from the process centre to the nearest specification limit divided by a measure of the process variability. The idea is illustrated graphically in Figure 1.

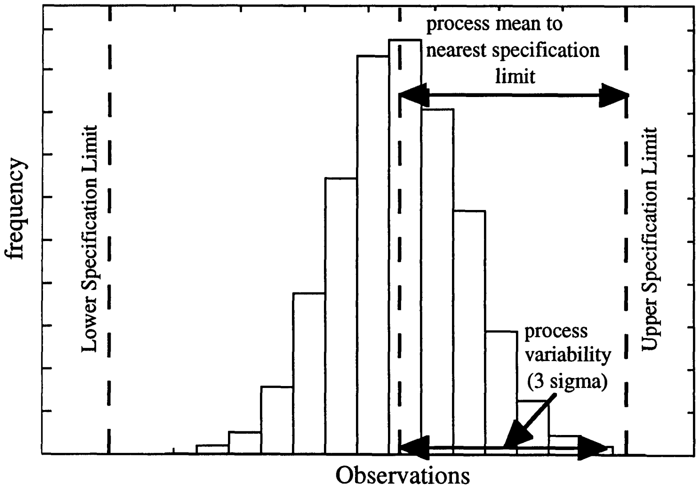

Figure 1: Graphical Illustration of Process Capability

In more mathematical terms,

$$\text{Process Capability} = \min\left(\frac{USL-\mu}{3\sigma}, \frac{\mu - LSL}{3\sigma}\right),$$

where USL and LSL are the upper and lower specification limits respectively, and μ and σ are the process mean and standard deviation for individual measurements of the characteristic of interest respectively. To calculate the process capability requires knowledge of the process mean and standard deviation, μ and σ. These values are estimated from data collected from the process.

Often the process data is collected in subgroups. Let X_{ij}, $i=1,\ldots,m$ and $j=1,\ldots,n$ represent the process data collected from the j^{th} unit in the i^{th} subgroup. Here, m equals the total number of subgroups, and n equals the subgroup sample size. The two most important capability indices used in the QS-9000 standard are both estimates of the process capability. They are defined as:

$$P_{pk} = \min\left(\frac{USL-\overline{\overline{X}}}{3\hat{\sigma}_s}, \frac{\overline{\overline{X}}-LSL}{3\hat{\sigma}_s}\right) \tag{1}$$

$$C_{pk} = \min\left(\frac{USL-\overline{\overline{X}}}{3\hat{\sigma}_{\overline{R}/d_2}}, \frac{\overline{\overline{X}}-LSL}{3\hat{\sigma}_{\overline{R}/d_2}}\right), \tag{2}$$

where $\overline{\overline{X}}$, the overall average, is used to estimate the process mean μ, and $\hat{\sigma}_s$ and $\hat{\sigma}_{\overline{R}/d_2}$ are different estimates of the process standard deviation σ.

The estimate $\hat{\sigma}_s$ is the sample standard deviation $\sqrt{\sum_{j=1}^{n}\sum_{i=1}^{m}\left(X_{ij}-\overline{\overline{X}}\right)^2 \Big/ (nm-1)}$, whereas $\hat{\sigma}_{\overline{R}/d_2} = \overline{R}/d_2$ is an estimate derived using the subgroup ranges R_i, $i=1,\ldots,m$. The parameter d_2 is an adjustment factor needed to estimate the process standard deviation from the average sample range. Since d_2 is also used in the derivation of control limits for $\overline{X}$ and R control charts it is tabulated in standard references on statistical process control, such as the QS-9000 SPC manual or Montgomery (1991). Large values of C_{pk} and P_{pk} should correspond to a capable process that produces the vast majority of units within the specification limits.

The capability index P_p is also mentioned in the QS-9000 standard. The index P_p, and the related index C_p, are similar to C_{pk} and P_{pk}. However, P_p and C_p ignore the current estimate of the process mean and relate the specification range directly to the process variation. In effect, C_p and P_p can be considered measures that suggest how capable the process could be if the process mean were centred midway between the specification limits. The indices P_p and C_p are not recommended for reporting purposes, and as a result only the indices C_{pk} and P_{pk} are considered in more detail in this article. For more information on other process capability measures see Kotz (1993).

To illustrate the calculation of the estimated capability indices C_{pk} and P_{pk} we present a simple example. In this example, called the Pilot OD example, the diameter of the pilot on an output shaft is a special characteristic. The upper and lower specification limits for the diameter are $USL = 25$ and $LSL = -25$ respectively, when the measured quantity is the number of microns from nominal. A previous study verified that the measurement system utilized introduces very little measurement error. As part of a PPAP demonstration study, 300 units were produced. The data were classified into 25 subgroups of four observations each by measuring the diameters of the first four units in each batch of twelve units. Table 1 gives the 100 recorded data observations. Figure 2 is a histogram of the 100 data points, and shows a normal shape with no observations outside the specification limits.

Table 1: Pilot OD Data

subgroup	1	2	3	4	$\bar{X}_i$	R_i
1	–10	–6	0	0	–4.0	10
2	–14	–4	–6	4	–5.0	18
3	–2	12	–2	8	4.0	14
4	–4	–6	–6	–2	–4.5	4
5	12	6	2	2	5.5	10
6	0	0	–6	–8	–3.5	8
7	2	–6	8	–6	–0.5	14
8	0	6	4	8	4.5	8
9	2	4	6	8	5.0	6
10	–8	0	–4	2	–2.5	10
11	4	2	2	6	3.5	4
12	–8	4	–14	6	–3.0	20
13	–10	2	–10	4	–3.5	14
14	–8	2	–4	4	–1.5	12
15	6	16	10	18	12.5	12
16	2	2	0	2	1.5	2
17	12	6	0	2	5.0	12
18	2	2	0	–8	–1.0	10
19	–6	–4	2	0	–2.0	8
20	–2	4	0	4	1.5	6
21	2	4	2	6	3.5	4
22	0	4	2	4	2.5	4
23	–2	4	–2	4	1.0	6
24	–10	4	–12	4	–3.5	16
25	6	8	–4	2	3.0	12

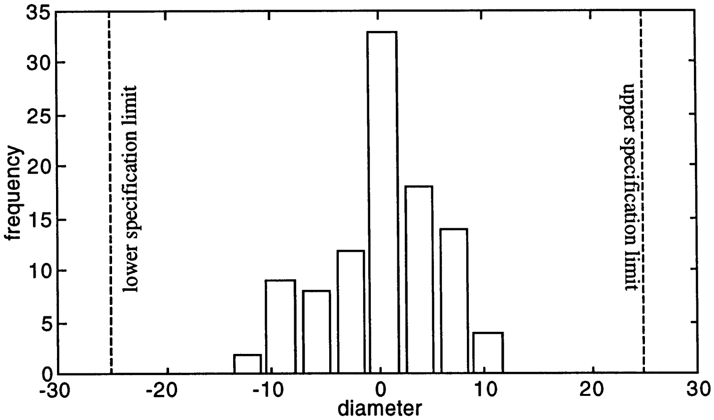

Figure 2: Histogram of Pilot OD data

Figure 3 shows the corresponding $\overline{X}$ and R control charts. There is one out-of-control point on the $\overline{X}$ chart corresponding to subgroup 15.

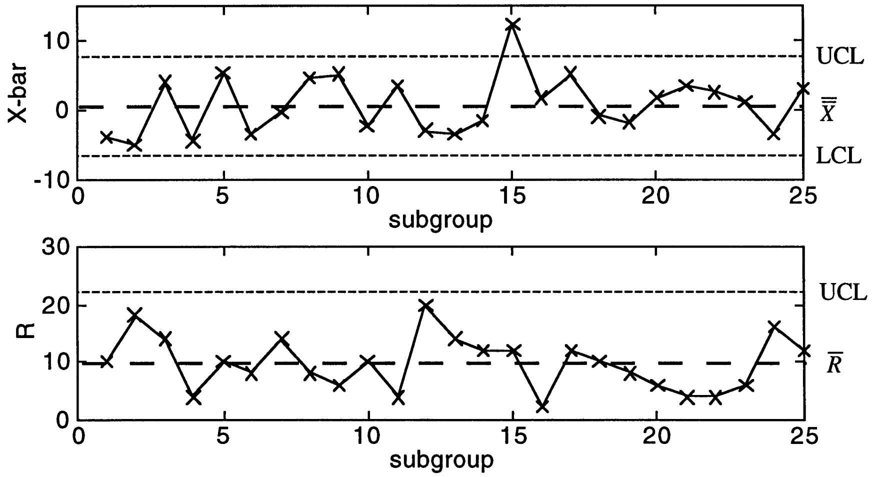

Figure 3: $\overline{X}$ and R control charts from Pilot OD example

Based on the data in Table 1 we calculate the following quantities: $\overline{\overline{X}}$ = 0.74, $\overline{R}$ = 9.76, and $\hat{\sigma}_s$ = 6.11. Since, in this example, the subgroup size equals four, d_2 = 2.059 and thus $\hat{\sigma}_{\overline{R}/d_2}$ = 4.74. Using the definitions (1) and (2) yields C_{pk} = min(1.81, 1.71) = 1.71 and P_{pk} = min(1.40, 1.32) = 1.32. In this case, C_{pk} and P_{pk} are quite different, and lie on different sides of the key cutoff values 1.33 and 1.67 given in the PPAP manual.

As shown in (1) and (2), the measures C_{pk} and P_{pk} differ only in the estimate of the process standard deviation used in the denominator. As a result, to compare the two capability measures we need only compare the two standard deviation estimates $\hat{\sigma}_{\bar{R}/d_2}$ and $\hat{\sigma}_s$.

There is one important differences between $\hat{\sigma}_{\bar{R}/d_2}$ and $\hat{\sigma}_s$. Since the range-based estimate $\hat{\sigma}_{\bar{R}/d_2}$ is calculated based on subgroup ranges, it uses only the variability within each subgroup to estimate the process standard deviation. The sample standard deviation-based estimate $\hat{\sigma}_s$, on the other hand, combines all the data together, and thus uses both the within subgroup and between subgroup variability. The total variation in the Pilot OD process is the sum of the within subgroup and between subgroup variability. As a result, $\hat{\sigma}_s$ estimates the total variation present in the process while $\hat{\sigma}_{\bar{R}/d_2}$ estimates only the within subgroup variation.

The question of which estimate provides a more appropriate measure of process variability to use in the process capability calculation can be answered by taking a customer perspective. This is because a major purpose of capability indices is for customer reporting. Customers are concerned about all the variation in the process output, regardless of its source. As a result, from the customer's perspective, the capability of a process should be based on the process' total variation, i.e. we should use the capability index P_{pk}. C_{pk} seriously underestimates the total variation if the between subgroup variability is substantial. This is illustrated in the Pilot OD example where the lack of stability, shown by the out-of-control point on the $\bar{X}$ chart, is evidence of substantial between subgroup variability.

Note that in all cases of practical interest the estimate $\hat{\sigma}_s$ is larger than $\hat{\sigma}_{\bar{R}/d_2}$, since $\hat{\sigma}_s$ includes the between subgroup variability in the calculations. Thus, P_{pk} tends to be smaller than C_{pk}, and using P_{pk} rather than C_{pk} makes the process "look worse." For this reason, suppliers may be reluctant to use P_{pk} rather than C_{pk}. However, it is beneficial for both parties to obtain a realistic view of the capability of the process to produce parts within specification.

To further illustrate the differences and similarities between C_{pk} and P_{pk} we consider the Pilot OD data with some small changes. By definition the subgroup range-based estimate $\hat{\sigma}_{\bar{R}/d_2}$ is unaffected by changes to the individual observations that do not change the subgroup ranges. For example, subtracting 12.5 from all observations in the 15th subgroup of the Pilot OD example has no effect on R_{15}, and thus has no effect on $\hat{\sigma}_{\bar{R}/d_2} = \bar{R}/d_2$. If, in addition, the global average $\bar{\bar{X}}$ is unchanged, the capability index C_{pk} given by (2) will be unaffected. Figure 4 shows the resulting $\bar{X}$ and R control charts when 12.5 is subtracted from all observations in subgroup 15, and 6.25 is added to all observations in subgroups 1 and 2. The control charts now suggest a stable process.

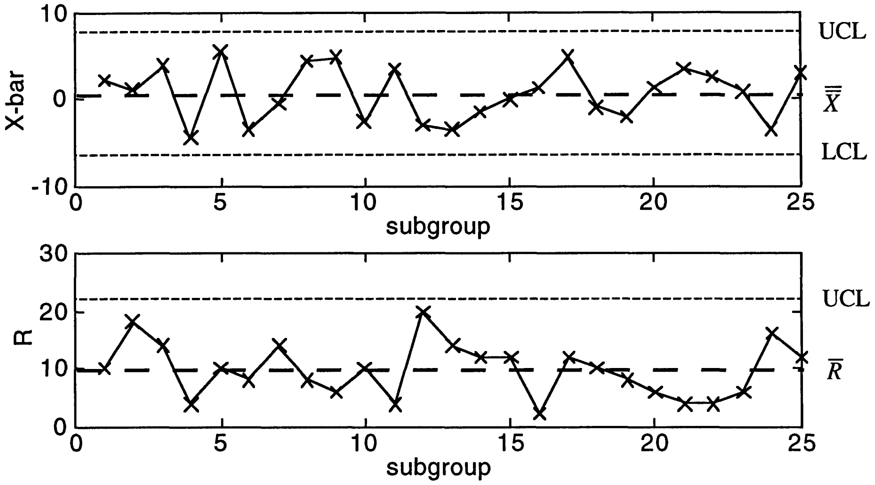

Figure 4: $\bar{X}$ and R control charts from altered Pilot OD data

With the suggested changes to the data, $\bar{\bar{X}}$ is still 0.74, $\hat{\sigma}_{\bar{R}/d_2}$ still equals 4.74, and thus C_{pk} is unchanged at 1.71. However, now $\hat{\sigma}_s = 5.45$, and thus P_{pk} equals 1.48. C_{pk} and P_{pk} are closer since the between subgroup variability has been reduced. The small amount of between subgroup variation is also shown by the in-control $\bar{X}$ control chart. In general, for stable processes C_{pk} and P_{pk} will be similar. However, even for stable processes, P_{pk} is a better measure of capability since the small amount of between subgroup variability still contributes to the total variability in the process output.

The standard deviation estimates $\hat{\sigma}_s$ and $\hat{\sigma}_{\bar{R}/d_2}$ also differ in a less fundamental, but also important, way. The subgroup range-based approach yields estimates that are not as efficient as the sample standard deviation method even if the between subgroup variation is zero. For example, in a capability study that uses 100 observations divided into 25 subgroups the range-based method has an efficiency of only approximately 86% compared with the sample standard deviation method. This loss of efficiency results mostly from a loss of degrees of freedom, and means that when using the range method, process information is discarded needlessly. The less efficient range-based estimate is popular since it is used in control charts and can be calculated easily by hand.

3. Issues Relating to Capability Indices

This section provides a discussion of various important issues relating to the calculation and interpretation of capability indices in the context of the QS-9000 standard.

3.1 Process View (Sampling Scheme)

As shown in (1) and (2), the capability of a process is estimated from collected data that represents a sample of the total production. Clearly, as a result, the capability indices C_{pk} and P_{pk} are greatly influenced by the way in which the process data are collected, what we will call the process view. A process view is defined by the time frame, and sampling method (sampling frequency, sample size, etc.) used to obtain the process data. Using an appropriate process view is crucial since different views can lead to very different conclusions. For example, in one view the process may appear stable, while in another the process appears unstable.

To define the process view, the first choice involves the time frame over which process data will be collected. Often the time frame is stipulated by the customer as a reporting interval. For example, the capability of each important process characteristic may be reported every quarter. In other situations, such as for characteristics subject to PPAP requirements, the time frame is restricted to a shorter interval, such as the production period needed to produce 300 units. To obtain a reasonable measure of the process capability, the length of the time frame should be chosen so that it is long enough to reflect all the substantial sources of variation in the process (see Ongoing Process Capability entry in the Glossary of the QS-9000 manual).

Defining the sampling method or procedure is also important. The process output is sampled in such a way that we obtain a "fair" representation of the process over the chosen time frame. For the capability calculations, it is not necessary for the samples to be collected in subgroups. However, since subgroups can also be used to create control charts that may be helpful in managing the process, subgrouping of the data is recommended.

To illustrate the importance of the sampling procedure, or process view, consider a tool wear example. Figure 5 shows the output of the process over a selected time frame for every part produced. The tool replacement times are clearly visible. We can sample in such a way that the process appears stable and the process capability appears high. For example, taking a subgroup of size five from the start of each tool cycle likely results in a stable control chart, since at the start of each tool cycle the process mean is close to 10. Calculating P_{pk} based on the data from this process view would lead to a large value, since the process variation at the start of each tool cycle is small compared with the distance to the upper specification limit.

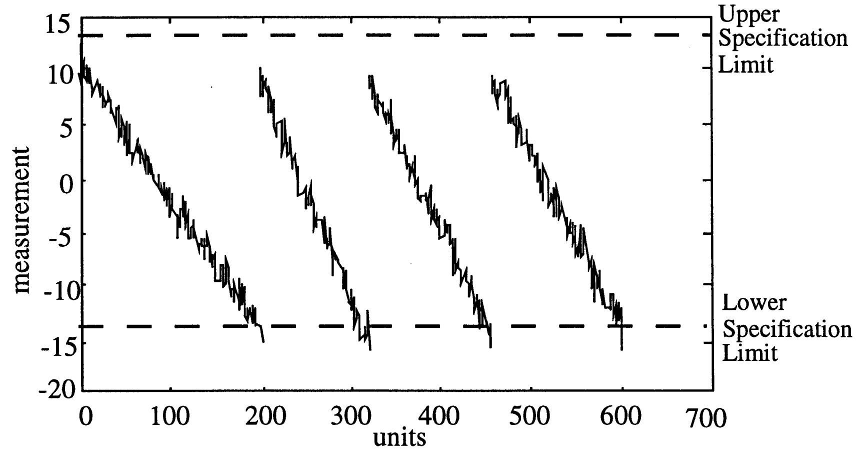

Figure 5: Tool Wear Example

However, sampling from the process in this way is not a fair representation of the output of this process, and thus P_{pk} calculated from this data does not accurately represent the process capability. This is clearly shown by the out–of–specification units produced at the end of each tool cycle. In this tool wear example, to obtain a "fair" representation of the process we should sample throughout one or more tooling cycles.

By changing the process view the conclusions about the process' capability can be reversed. As a result, more specific guidelines regarding the time frame, and the sampling method used to collect the data for the process capability calculations should be addressed in Section 4.9.3 of the QS-9000 standard. Section 4.9.3 could reference Appendix A of the SPC Manual where appropriate subgrouping is discussed.

Another important issue related to the process view is the number of data points used in the estimation. P_{pk} is an estimate of the process capability, thus even if the process is unchanged, taking another sample and recalculating the index is unlikely to yield precisely the same result. The amount of uncertainty is based on both the properties of the process and the number of data observations used to calculate the capability index. The estimates will tend to be better if we use more information about the process. In other words, larger sample sizes provide more information and thus tend to lead to better estimates of the process capability. However, the parts of the QS-9000 standard that relate to process capability, other than the PPAP manual, do not stipulate a minimum sample size requirement for the calculation of the capability indices. For a PPAP study, the QS-9000 standard requires a sample size of at least 100 units. QS-9000 should clearly state that all calculations of process capability should require samples of at least 100 observations.

3.2 Process Stability

The QS-9000 process capability requirements as quoted from Section 4.9.3 distinguish between three classes: stable, unstable and chronically unstable but predictable processes. A process is considered stable if all the points on its $\overline{X}$ and R control charts fall within the control limits, and there are no apparent patterns. A chronically unstable, yet predictable process is not clearly defined in the requirements. However, we believe the label is intended to encompass processes subject to tool wear whose output changes systematically. There are many applications that involve substantial and unavoidable tool wear, where, if properly managed, the process produces all the parts within the specification limits. All other processes are classified as unstable.

In the QS-9000 standard, process stability is considered an important property since if the process is stable in the current time frame it is likely to also be stable in the future, assuming that no major process changes are made. Thus, the total output of a stable process is in some sense predictable. If the output of a process is stable, then the process' capability is predictable from past performance. On the other hand, if the process output is not stable, it is possible that over time the process capability index is stable. For example, a process subject to tool wear is not stable, but if worn tools are replaced well before non-conforming units are produced the process should be consider very capability. As such, more reliable indicator of the predictability of the process capability can be obtained by considering the performance of the process in terms of its process capability over time. If the past process capability values exhibit a stable (or increasing if the quality is improving) pattern then we would have some confidence predicting future process capability indices.

In any event, setting aside the issue of process stability, we may examine the consequences of using the different capability indices C_{pk} and P_{pk}. As shown in the example, if the process is stable, C_{pk} is approximately equal to P_{pk}, since a stable process has little between subgroup variability. Thus, if the process is stable, it does not matter which measure is used. On the other hand, if the process is unstable, there is substantial between subgroup variability, and C_{pk} is not equal to P_{pk}. In this case, C_{pk} overestimates the process capability since it does not include the between subgroup variability. The same thing applies if the process is chronically unstable and yet predictable. As a result, in all situations, P_{pk} provides a better measure of the process capability than C_{pk}.

3.3 Different Distributions

A number of other assumptions are made when interpreting and comparing capability indices. As mentioned in the QS-9000 standard, process capability indices calculated from non–normal processes are not comparable with those from normal processes in terms of the proportion falling outside the specification limits. This difference is indicated in Figure 6. The figure shows the distribution of the output of two processes which have equal process means and standard deviations, and thus equal process capabilities, but yield different proportions of nonconforming units. As shown, the skewed process produces more out-of-specification parts than the process whose output is normally distributed. This means that the capability indices of processes whose output distributions are not similar should not be directly compared. As a result, using capability indices alone without checking the process distribution to prioritize improvement efforts can lead to poor choices.

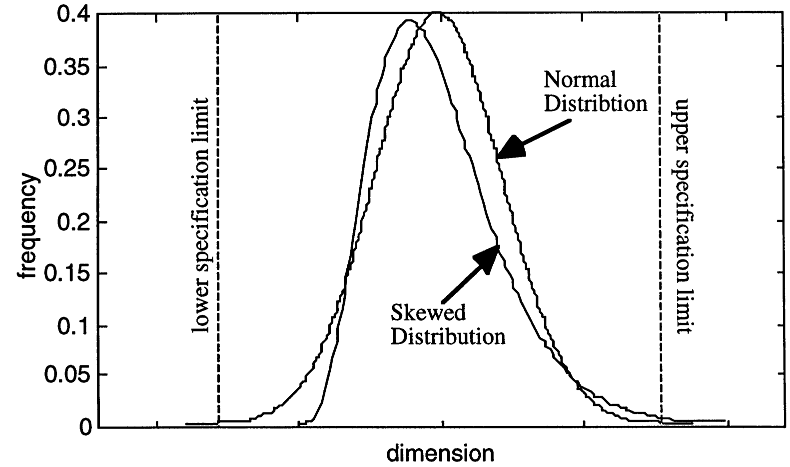

Figure 6: Normal versus Non–normal Distribution Plot

For this reason, plotting a histogram of the data used to calculate the capability index, as given in Figure 2, is always useful. A histogram of the data will show whether the normal assumption is reasonable, and may also provide information as to why the calculated index is not higher. For example, it may be evident that the process is not centred, or that there are a few outliers that have a large influence on the index. In addition, comparing the histograms of process data over time or of different processes will help to determine whether capability indices calculated from that data are comparable.

4. Guidelines for a Rewrite of Section 4.9.3 of the QS-9000 Manual

The intent of Section 4.9.3 in the QS-9000 manual is to explain how to provide data for special characteristics on an ongoing basis in order to monitor the behavior of the process. These data may arise as part of the process control plan but not necessarily so. Process control and process monitoring are two different functions required by the standard. All special characteristics must be dealt with by the control plan. Many processes will require a separate monitoring plan to meet customer needs.

From the customer perspective, monitoring the process can provide data to assure the supplier about the quality of product that has been shipped. In addition, the supplier can use the monitoring data to suggest process improvements, and both the customer and the supplier can evaluate the progress of continuous improvement efforts by tracking the summaries of the monitoring data.

The current version of section 4.9.3 of the QS-9000 standard is confusing for several reasons. First, the intent is not made clear. Is monitoring required for all special characteristics? Is regular reporting to the customer required? Second, the role of monitoring and process control are confounded. For example, the final part of the element deals with reaction plans to out-of-control signals from a control chart. Reactions plans are already part of the required control plan. In fact, it is not required to use a control chart as the control method for a special characteristic so that from a process control perspective, no control chart may exist. A third confusion arises because different capability measures are suggested, with differing acceptable values, depending on the nature of the process stability. Phrases such as "chronically unstable processes ... with predictable pattern" are not defined in the glossary. Also, there is no mention of time frame or sampling method for the required monitoring. Non–normal shape is treated as a separate issue with poorly defined requirements.

The supplier requires data to demonstrate both stability and capability of the process. To specify the monitoring scheme, the following questions must be considered:

- what is the time frame for the demonstration?
- what is the sampling method?
  - what is the appropriate subgrouping?
  - when and how often should these subgroups be collected?
  - how much data is needed?
- how should the data be reported?

A consistent time frame for monitoring is needed so that data are available to the customer on a timely basis while keeping the costs reasonable. Depending on volumes and past history of performance, a monthly report may be sufficient.

The goal of the sampling method is to produce data representative of performance of the process over the specified time frame. Sufficient data are required to reduce the errors of estimation. At least 100 data points (as in PPAP) should be required and these points should be collected in subgroups spread out through the time frame in some rational way.

For variables data, the minimal reporting requirements should be a control chart with limits calculated internally to show the nature of stability over the time frame, a histogram to show shape, and P_{pk} to compare performance to specifications. A run chart of P_{pk} over all past reporting periods would also be useful.

The standard should be rewritten to ensure that these questions are addressed. The confusion between monitoring and process control should be eliminated. Minimal requirements for ongoing process performance should match those required for PPAP approval. A simple statement such as $P_{pk} > 1.33$ will suffice as the default value for most characteristics.

Note that the time frame, sampling method and data reporting should stay the same over time so that improvement is visible to the supplier and customer. Improvement can be assessed in terms of better stability (fewer out of control signals) and larger P_{pk}.

5. Summary and Conclusions

Capability indices play an important part in quality reporting in general, and in QS-9000 standard specifically. The requirements given in QS-9000 are confusing to suppliers since many different definitions of process capability are used.

The QS-9000 standard is based on the capability indices P_{pk} and C_{pk}. P_{pk} considers the total variability in the output, while C_{pk} uses only the within subgroup variability. Customers are concerned with all the variability in the process output, and are not interested in distinguishing between different sources of variability. Thus, from a customer perspective, P_{pk} is always preferable to C_{pk}.

In addition, the time frame for which we wish to estimate the capability, and the sampling method used to collect the data needed to estimate the process capability are very important. The time frame is typically mandated by customer reporting requirements. To get a realistic measure of the process capability the process must be sampled in a way that is representative of the operation of the process. To ensure that unusual values are not given too much weight a minimum sample size requirement of 100 units should be specified.

Stability is another important issue. If the process output is stable, the capability tends also to be predictable, although the reverse is not necessarily true. As a result, the standard should emphasize the stability of the process capability indices over time, as well as the stability of the process output itself where appropriate.

Finally, to compare the capability of different processes, or the capability over time, the shape or distribution of the output is important. Non–normal processes are most easily identified through a histogram of the data.

As a result, the QS-9000 capability requirements should be rewritten solely in terms of the index P_{pk}. In addition, the requirement should highlight the importance of choosing an appropriate time frame and sampling procedure. Furthermore examining control chart of the process output, monitoring the process capability, and showing a histogram of the sample data should be required. These suggestions provide a basis for a rewrite of Section 4.9.3 of the QS-9000 reference manual.

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