Process Capability/Performance: Confusion and Resolution

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Measurements affect behavior. The wrong behavior results when metrics do not represent what is happening. The leaders of many respected companies are now paying the price for creating an environment in which measurements did not accurately reflect what was occurring in their organization. They created an environment in which it is common practice to play games with the numbers and to make short-term numbers look good at the expense of long-term performance for stockholders and employees. They did not have a strategy according to which high-level business measurements were tracked as a process, led to the creation of a meaningful strategic plan, and then aligned process improvement/re-engineering projects to this plan.

Measurement issues can be prevalent at all levels of an organization. To add to this dilemma, the metrics themselves can sometimes be deceiving. To illustrate this, consider the metrics of Six Sigma, which can be either very powerful or misleading. Organizations often state that suppliers must meet process capability and other Six Sigma metrics objectives. However, these organizations do not often realize that these reported numbers can be highly dependent upon how data are collected and interpreted. Because of this, an organization might feel compelled to play-games-with-the-numbers in order to look good and/or meet customer requirements. In contrast, the *wise* selection of metrics within a Six Sigma business strategy can lead to activities that result in performance excellence.

This article addresses the needs of organizations that want to have throughout their entire enterprise an effective measurement and improvement strategy which everybody understands and can support.

Process Capability/Performance

Process capability/performance studies assess a process relative to specification criteria. Statisticians have often challenged how well commonly used capability indices do this. However, customers often request these indices when communicating with their suppliers. Customers might set process capability/performance targets and then require their suppliers to meet these targets.

Equations to determine process capability indices are basically very simple. Process capability indices C_p and C_{pk} can be expressed as

$$C_p = \frac{\text{USL - LSL}}{6\sigma} \qquad C_{pk} = \min\left[\frac{\text{USL} - \mu}{3\sigma}, \frac{\mu - \text{LSL}}{3\sigma}\right]$$

In these equations, C_p compares the spread of data (6 times standard deviation, σ) to the width of the specification limits (Upper specification limit [USL] minus lower specification limit [LSL]). C_{pk} calculations include the mean of the process, μ, in its calculation, which addresses the non-centering of a process relative to specification limits.

However, these equations are very sensitive to the standard deviation parameter used in the equation. Let's now consider how one might determine the standard deviation of a process for use within these equations. There are differences of opinion on how this should be done.

To illustrate this, let’s consider five consecutive daily samples from a process, in which raw material batches changed daily. Consider also that this raw material difference impacted the output of our process. Figure 1 illustrates this scenario, where the seven small distributions that are shown describe within-day variability from this daily sub-group sampling plan, along with the between-day variability impact to the overall variability of the process.

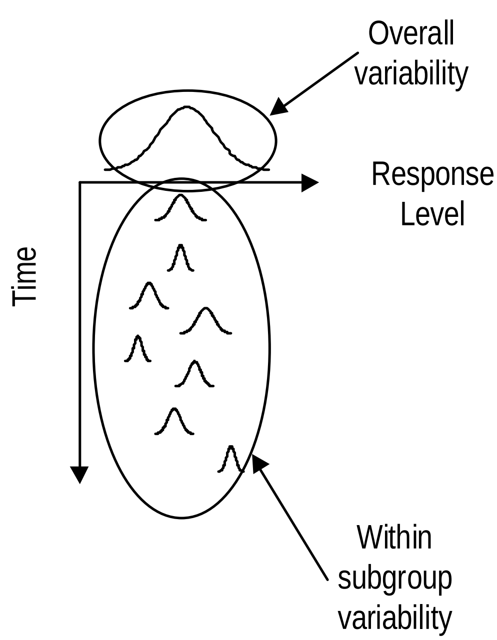

Figure 1

Typically when sampling from a process, if we make observations over a short period of time, we will often observe a smaller amount of variability within sampled lots than between sample lots. This within-subgroup variability is called short-term variability, while the combination of within-subgroup and between-subgroup variability is called overall variability. The question is whether we should focus on overall or within-subgroup variability for the above process capability assessment equations.

Some organizations use C_p and C_{pk} indices to reflect long-term variability. However, other organizations use C_p and C_{pk} indices to reflect short-term variability and P_p and P_{pk} indices to reflect long-term variability. The Automotive Industrial Action Group (AIAG) publication (1) uses this later differentiation, as described in their following definitions.

- Process Capability: The 6σ range of a process's inherent variation, for statistically stable processes only *where* σ *is usually estimated by* $\overline{R}/d_2$ [from an $\overline{x}$ and R control chart] (2).
- C_p: This is the capability index which is defined as the tolerance width divided by the process spread, irrespective of process centering.
- C_{pk}: This is the capability index, which accounts for process centering. It relates the scaled distance between the process mean and the closest specification limit to half the total process spread.
- Process Performance: The 6σ range of a process's total variation, *where* σ *is usually estimated by s, the sample standard deviation.*
- P_p: This is the performance index which is defined as the tolerance width divided by the process performance, without regard to process centering. Typically, this is expressed as the tolerance width divided by six times the sample standard deviation. It should only be used to compare to or with C_p and C_{pk} and to measure and prioritize improvement over time.
- P_{pk}: This is the performance index which accounts for process centering. It should only be used to compare to or with C_p and C_{pk} and to measure and prioritize improvement over time.

Long-term variability could be estimated from the relationship

$$\hat{\sigma} = \sqrt{\sum_{i=1}^{n} \frac{(x_i - \overline{x})^2}{n-1}}$$

where $\hat{\sigma}$ is the standard deviation estimate, x_i are individual sample datum points, $\overline{x}$ is the sample average, and n is the sample size.

If data are collected from an $\overline{x}$ and R chart (2), short-term variability could be determined from the relationship

$$\hat{\sigma} = \frac{\overline{R}}{d_2}$$

where $\overline{R}$ is the range from an $\overline{x}$ and R chart and d_2 is a tabular value (2).

If data are collected from an *XmR* chart (2), short-term variability could be determined from the relationship

$$\hat{\sigma} = \frac{\overline{MR}}{d_2} = \frac{\overline{MR}}{1.128}$$

where $\overline{MR}$ is the moving range and d_2 is a tabular value.

Note

For the process described in the above graphic, someone could chose a subgroup sample size of one and create an XmR chart. As an alternative, he/she could have chosen a subgroup sample size of five and created an $\overline{x}$ and R chart. It is important to note from the above equations that these two differing process sampling procedures would yield a different result for short-term variability.

Some statistical software packages use the above equations to differentiate between short-term and long-term variability. However, other statistical software packages and calculation procedures do not make this differentiation. This confusion gets amplified when we consider the differences that can result from how frequently a process is sampled to make the calculation, as described above. Because of these differences, a company can make a wrong decision through the determination, interpretation, and comparison of these indices.

Other issues that compound this confusion is that the described equations are for normally distributed data. Computer programs can often address situations in which data are not from a normal distribution; however, this does not often occur in practice and can affect the accuracy of the reported metrics. In addition, sample size, confidence intervals, and not having samples taken from the population of interest can distort results. Finally, these indices are not typically appropriate when the data are attribute (e.g., a product either passes or fails a criterion), which is typically expressed as a part-per-million (ppm) defective rate or a percent defective rate.

Sigma Quality Level

Another commonly reported Six Sigma metric is sigma level or sigma quality level. With this metric a six sigma quality level translates to a 3.4 parts per million (ppm) defect rate. Other conversions are

- 5 sigma quality level translates to 233 ppm
- 4 sigma quality level translates to 6210 ppm
- 3 sigma quality level translates to 66,811 ppm

- 2 sigma quality level translates to 308,770 ppm

Claims are sometimes made that through the sigma quality level metrics all functions within organizations can be compared. This claim can sound very attractive to executive management. However, in practice this metric can yield deceiving results.

For one thing, the metric is not linear. That is, the change from 3.0 to 3.1 is quite different than it is from 5.0 to 5.1. This can cause much confusion when explaining the status of work and why it is taking so much longer to improve an incremental amount of 0.1 when the sigma quality level reaches a higher value. For this type of metric, we suggest leaving the defective rate in units of ppm with a conversion to a monetary rate whenever possible.

Even more confusion can occur for other situations. A specification is required to make a sigma quality level calculation. In a transactional environment, an attempt is made to quantify customer desire, which is then used as a specification to perform these calculations. This transactional specification is not the same thing as it is in manufacturing, where, for example, a shaft can have an interference fit within a journal bearing when it is larger than its upper specification limit.

To elaborate on this point further, consider the on-time departure time "specification" for the airline industry of 15 minutes from the scheduled departure time. If an airline has a departure time 16 minutes late or 3 hours late, the flight is equally considered late. As a customer, are you equally dissatisfied with both these situations? If you are not, perhaps a metric should be created that more accurately reflects our opinion as customers.

Answering the Right Question

The section above addresses some measurement issues; however, there is another issue that needs to be addressed: Are we answering the right question? It is important to align our measurements and improvement activities to the overall needs of the business. Organizations need to create a set of balanced cascading measurements that lead to meaningful activities, which gets organizations out of the fire-fighting mode. In Smarter Solutions, Inc. we call this approach *Smarter Six Sigma Solutions*℠ (*S^4* ℠) or *Integrated Enterprise Excellence (IEE*). With this approach, *30,000 Foot-Level*℠ operational metrics are aligned with *Satellite-Level*℠ metrics, which track the business as a process.

This approach differs from the common practice of giving emphasis to just comparing current-quarter to a last-quarter or a similar quarter from a previous year. *Satellite-level* metrics track key metrics such as return on invested capital as a process using an infrequent sub-grouping/sampling plan, in which an *XmR* chart might track the monthly results as a process output over several years.

With this *S^4/IEE* approach, organizations can create strategic plans that are aligned with the improvement needs of the *Satellite-Level* metrics, as shown in Figure 2.

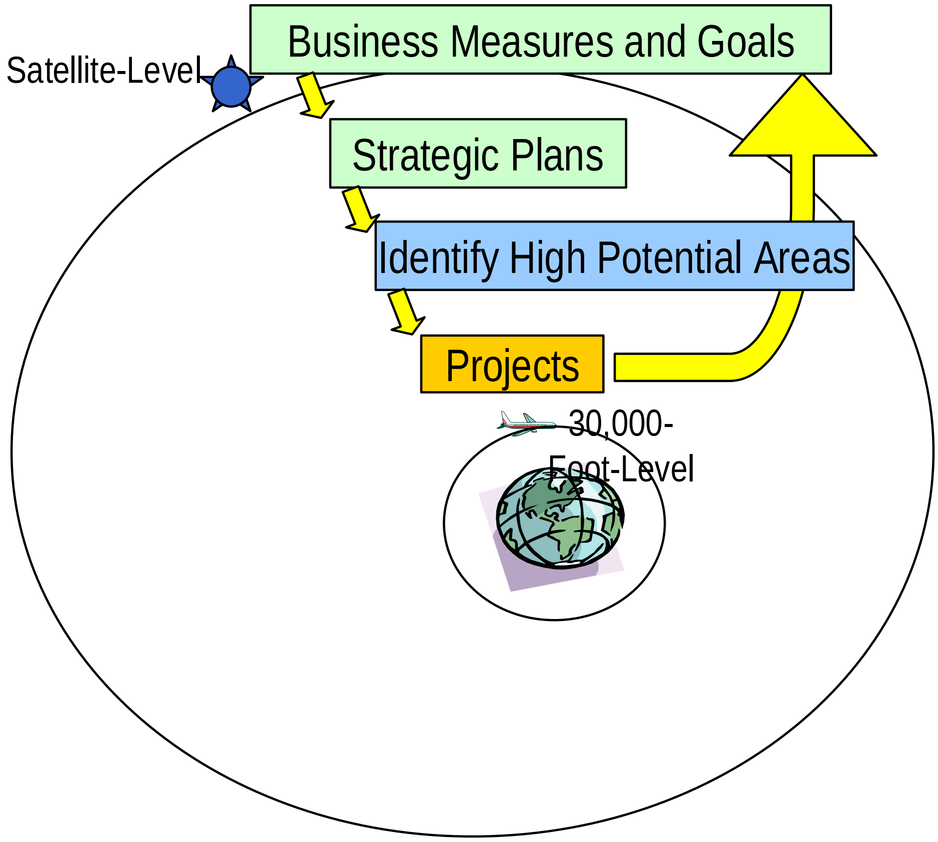

Figure 2

Organizations can then create specific *S⁴/IEE* projects that are targeted to these plans. These improvements can then be tracked and quantified at the *30,000 Foot-Level*. Successful projects will experience a statistical significant change in the process capability/performance at the operational level, which would have a positive impact on the *Satellite-Level* metrics.

However, to quantify these improvements, we need a basic measurement strategy that leads to consistent results. In addition, the measure needs to be in units that are understandable and independent of the person who created the sampling plan.

A Resolution for Process Capability/Performance Reporting

An S^4*/IEE* approach is in alignment with the statement made by Edwards Deming that 94% of the problems experienced are from common cause issues (2). With an S^4*/IEE* approach we would view the day-to-day raw material variability that was described earlier as a noise variable that is common cause. Because of this, we need a measurement strategy that considers the between-day variability when establishing control limits for a control chart. This does not occur with a traditional $\bar{x}$ and R chart.

With an S^4*/IEE* approach we would track the process using an *XmR* chart that has an infrequent sub-grouping/sampling plan in which the typical noise variation of the process occurs between samples; this is what is meant by the word "infrequent." It should be noted that the purpose of the *30,000 Foot-Level* metric is not to give timely control to a process or give understanding of what could be causing unsatisfactory process capability/performance. The only intent of this metric is to give us a high-level picture of what the customer of the process experiences and to separate common cause from special cause variability.

For this high-level view of the process of a process, we can then quantify the capability/performance of the process in a form that everyone understands. If no specification exists, an 80% frequency of occurrence band, for example, could be quantified. When specifications or non-conformance regions do exist, we would determine the capability of the process in some form of proportion units beyond the criteria (e.g., ppm, dpmo, or percent non-conformance), along with a related Cost of Poor Quality (COPQ) or the Cost of Doing Nothing Differently (CODND) monetary impact. The COPQ/CODND metric along with any customer satisfaction issues can then be assessed to determine whether improvement efforts are warranted.

With an S^4*/IEE* strategy when improvement efforts are needed, there would be a "pull" for the creation of a project. Note that I am using the word "pull" as a lean term (2); i.e., in a manufacturing environment the customer and downstream process steps are to pull for the creation of product. This is different from many Six Sigma strategies in which projects are "pushed" into the system, leading to projects that are sub-optimizing processes and do not positively impact the overall company's enterprise.

The execution of an S^4*/IEE* project would then follow a 9-step Define-Measure-Analyze-Improve-Control (DMAIC) roadmap. At the end of the project the benefits would then be determined. This overall approach is illustrated in Figure 3 for a continuous response output, where the normal probability density function curve initially indicated an initial non-compliance rate of about 30%.

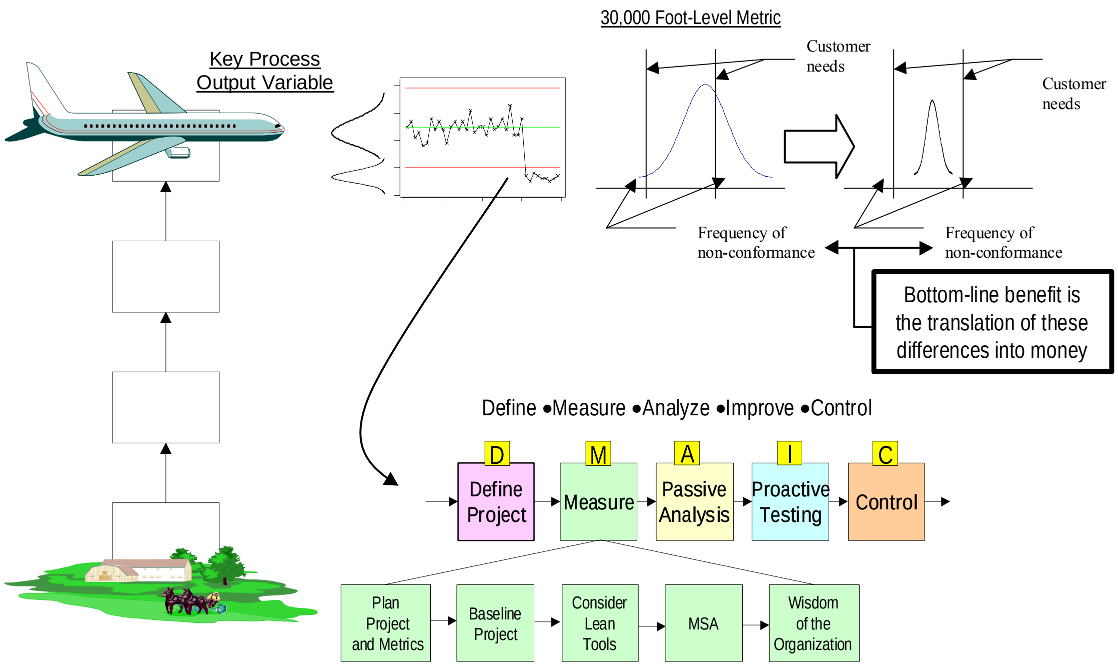

Figure 3

This basic approach also applies to the tracking of attribute data. Note that with this *S⁴/IEE* strategy we now have the opportunity for a consistent metric for both attribute and continuous data; i.e., ppm, dpmo, or percent non-conformance rate. (2, 3, 4, 5)

Implementing Six Sigma

Some Six Sigma practitioners make it a standard practice to compare short-term process capability to long-term process performance directly for all Six Sigma projects. They then use this difference to affect their project activities. Since these differences would be fallout from our *S⁴/IEE* project execution roadmap (if this difference were statistically significant), we do not believe that there is much gain for process improvement efforts by making such a routine comparison, which can be very costly.

Finally, with our *S⁴/IEE* approach we also do not recommend converting ppm rates to sigma quality levels because the results lead to confusion (2). The 1.5 standard deviation shift that is buried within a sigma quality level metric is confusing to many and distorts interpretations and comparisons between other process metrics. In addition, this conversion can become a very large issue when organizations must fabricate specification requirements in order to determine their sigma quality levels for processes that do not naturally have specification limits.

Six Sigma can help organizations improve their bottom-line and customer satisfaction; however, its effectiveness is a function of how *wisely* the metrics and project execution strategy are implemented.

Conclusion

It is important for organizations to build awareness of the exposures when using the described metrics in their Six Sigma training and coaching. I have found that most people find it easy to visualize and interpret an estimated ppm rate beyond customer objectives/specifications as a reported process capability/performance index. Because of this, I encourage organizations to consider using this metric with appropriate data transformations, in lieu of C_p, C_{pk}, P_p, and P_{pk} and other process metrics, whenever possible. Another benefit of this approach is that there can now be a single unit of measure for both attribute and continuous data situations within manufacturing, development, and transactional processes. Finally, this procedure can be used to describe processes in which the process output is not normally distributed, which is the nature of many processes; e.g., days-sales-outstanding.

To be successful, a Six Sigma business strategy needs a sound infrastructure leading to the selection of projects that are linked to the goals and metrics of the overall business. A high-level *XmR* control chart can be a very useful Six Sigma metric to do just that. This metric can get organizations out of the fire-fighting mode and into fire prevention mode through an S^4/*IEE* business strategy. This metric coupled with an effective project execution roadmap can lead to significant bottom-line benefits and improved customer satisfaction for an organization.

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About the Author

Forrest W. Breyfogle III is president of Smarter Solutions, Inc., which he founded in 1992 after a 24-year career at IBM. Smarter Solutions® is an international company that *wisely* integrates Six Sigma with Lean, Theory of Constraints, and other business strategies, helping customers improve both their bottom-line and customer satisfaction. Breyfogle is the author or co-author of several management and/or practitioner Six Sigma/Lean books and was the Subject Matter Expert (SME) for a Six Sigma benchmarking study conducted by APQC in 2001. Breyfogle earned a BS degree in mechanical engineering at the University of Missouri at Rolla and a MS degree in mechanical engineering at the University of Texas. He is an ASQ Fellow. He can be reached at forrest@smartersolutions.com or at 512-996-8288.

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