MINI-PAPER

Performance Metric Reporting at the 30,000-Foot-Level: Resolving Issues with $\bar{x}$ and R Control Chart and Process Capability Indices Reporting

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Wikipedia states:

> Control charts are a statistical process control tool used to determine if a manufacturing or business process is in a state of control. If analysis of the control chart indicates that the process is currently under control (i.e., is stable with variation only coming from sources common to the process), then no corrections or changes to process control parameters are needed or desired. In addition, data from the process can be used to predict the future performance of the process. If the chart indicates that the monitored process is not in control, analysis of the chart can help determine the sources of variation, as this will result in degraded process performance. A process that is stable but operating outside of desired (specification) limits (e.g., scrap rates may be in statistical control but above desired limits) needs to be improved through a deliberate effort to understand the causes of current performance and fundamentally improve the process.

Many organizations have benefited from control charts since the tool was invented by Walter A. Shewhart while working for Bell Labs in the 1920s; however, over the years it seems to me that there has been a decline in the tool's usage. The question that one might ask is what could drive a usage-frequency decrease?

One potential underlying reason for this lack-of-usage question is that control-charting usages can be violating underlying mathematical presumptions for the chart's application. The misalignment of control charting math with what is needed for a process stability assessment can result in firefighting common-cause variation as though it were special cause. If this were the case, an organization might conclude after some period of time that control charting techniques were not beneficial.

In addition to assessing process stability, one should also note that Wikipedia also states "data from the process (i.e., when stable) can be used to predict the future performance of the process." A follow-up question to this statement might then be: how should this prediction statement be determined and reported to others?

This paper addresses the above-described potential control charting assumptions and an approach to provide a prediction statement. Focus in this article will be given to data that would typically be charted using an $\bar{x}$ and R control chart; however, many of the basic concepts also apply to individuals charts, p-charts, c-charts, and u-charts.

This document describes a 30,000-foot-level alternative reporting approach[1] that addresses how to:

- Create control charts so that the chart-creation mathematics is consistent with a team's belief as to what fundamentally should be considered the source of common-cause variability and special-cause occurrence(s).
- Determine and report-out a process prediction statement whenever a process is stable when viewed from the 30,000-foot-level. This prediction statement is to be written so that everyone can easily interpret its meaning and be provided even when there is no specification.
- Provide in one visual report-out the process stability assessment along with a prediction statement, when appropriate.

Separation of Special-cause from Common-cause Variability

For a given process, one would think that everyone (when creating a control chart) would make a similar conclusion relative process stability and its capability/performance, where the only difference is from sampling probability (i.e., samples will differ by "luck of the draw"). However, this is not necessarily true. With a traditional approach, process statements are not only a function of process characteristics and sampling-chance differences but can also be dependent upon sampling approach.

This sampling-difference issue can have dramatic implications:

- One person could describe a process as not being in control, which would lead to activities that are to immediately address process perturbations as abnormalities, while another person could describe the process as being stable. For this second interpretation, the described perturbations would be perceived as fluctuations typically expected within the process. Any long-lasting improvement effort for this second type of process response involves looking at the whole process to determine what might be done differently to enhance the process' performance.
- One person could describe a process as not predictable, while another person could describe output response as predictable.

To illustrate how different interpretations can occur, let's consider the process time series data in Table 1[2,3]. In this table, each subgrouping interval contained five samples, where only ten subgroups are shown to simply the illustration.

This type of data traditionally leads to an $\bar{x}$ and R control chart, as shown in Figure 1 when determining if the process is in control or not. If the process were determined to be in-control, process capability indices are then might be used to provide

Subgroup	Sample One	Sample Two	Sample Three	Sample Four	Sample Five
1	102.7	102.2	102.7	103.3	103.6
2	108.2	108.8	106.7	106.6	109.1
3	101.9	103.0	100.6	101.4	101.3
4	103.9	105.5	104.3	104.5	104.5
5	97.2	99.0	96.5	94.9	96.5
6	94.4	93.0	93.0	95.2	93.6
7	104.7	103.6	103.7	104.7	104.5
8	102.5	102.7	101.2	100.6	103.1
9	101.9	103.1	101.0	101.2	101.4
10	95.0	95.3	95.3	94.4	94.2

Table 1: Process Time Series Data

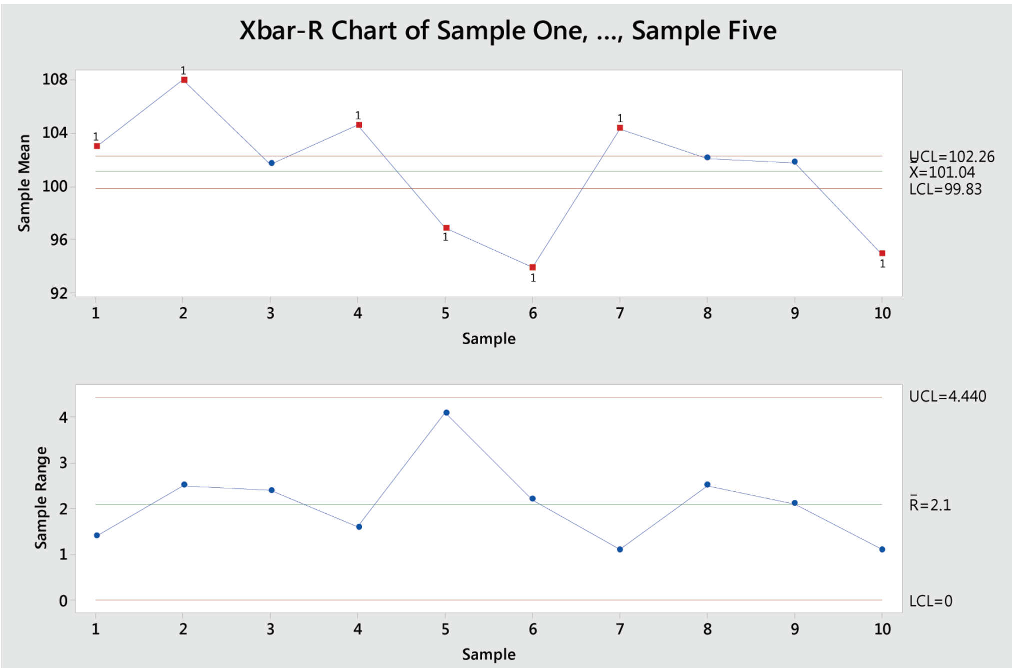

Figure 1: $\bar{x}$ and R Control Chart

how the process is performing relative customer specifications; e.g., 95 and 105 lower and upper specification limits for this example.

Whenever a measurement on a control chart is beyond the upper control limit (UCL) or lower control limit (LCL), the process is said to be out of control. Out of control conditions are considered special cause events, where these out-of-control conditions can trigger a causal problem investigation. Since so many out-of-control conditions are apparent in Figure 1, many causal investigations could have been initiated. When a process is out of control, no process capability statement should be made about how the process is performing relative to its specification limits.

However, when creating a sampling plan for the above described situation, one could have select only one sample, instead of several samples, for each sampling time period. For this sampling approach illustration, consider that only the first measurement was observed for each of the 10 sampling intervals. An *XmR* control chart, as shown in Figure 2, would be an appropriate method to assess process stability for this situation.

Relative to providing a process control statement, the *XmR* control chart in Figure 2 provides a very different view when assessing process stability assessment than that provided by the $\bar{x}$ and *R* chart shown in Figure 1. Since the plotted values in Figure 2 are within the control limits, one would conclude from this plot that only common cause variability exists and the process should be considered to be stable or predictable.

The dramatic difference between the limits of these two control charts is caused by the differing approaches to determining sampling standard deviation, which is a term involved in the calculation of statistical control limits. To illustrate this difference, let's examine how these two control chart limit calculations are determined.

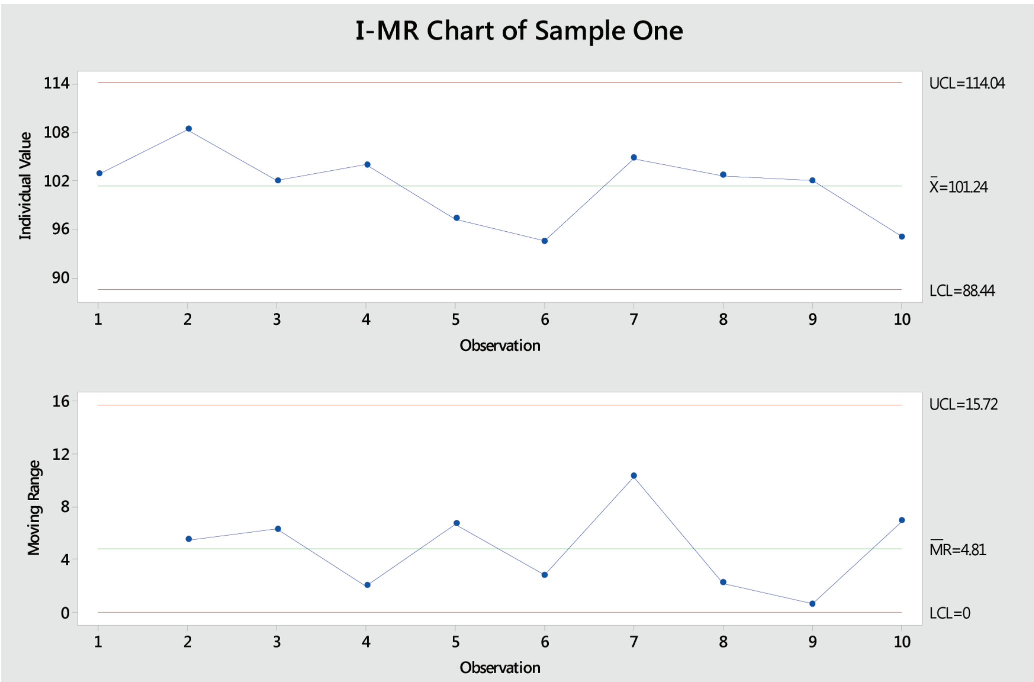

Figure 2: XmR Chart of Sample One

For $\bar{x}$ charts (from an $\bar{x}$ and R chart pair), the UCL (upper control limit) and LCL (lower control limit) are calculated from the relationships

$$\text{UCL} = \bar{\bar{x}} + A_2 \bar{R} \qquad \text{LCL} = \bar{\bar{x}} - A_2 \bar{R}$$

where $\bar{\bar{x}}$ is the overall average of the subgroups, A_2 is a constant depending upon subgroup size and $\bar{R}$ is the average range within subgroups.

For an X chart (from an XmR chart pair), the UCL and LCL values are calculated from the relationships

$$\text{UCL} = \bar{x} + 2.66(\overline{\text{MR}}) \qquad \text{LCL} = \bar{x} - 2.66(\overline{\text{MR}})$$

where $\overline{MR}$ is the average moving range between adjacent readings.

The control limits for the $\bar{x}$ chart are derived from within-subgroup variability ($\bar{R}$), while sampling standard deviations for an X chart is calculated from between-subgroup variability ($\overline{MR}$).

A process capability analysis of the data collectively would yield the output shown in Figure 3.

From Figure 3, one observes two standard deviations. The distribution that has a small standard deviation originates from the within subgroup variability of the process. Within subgroup variability is the variation used to determine the control limits for an $\bar{x}$ and R control chart. This is the basic reason that the control limits in Figure 1 are narrow relative to the spread of the plotting for the data's mean and range statistics in the control-chart plots.

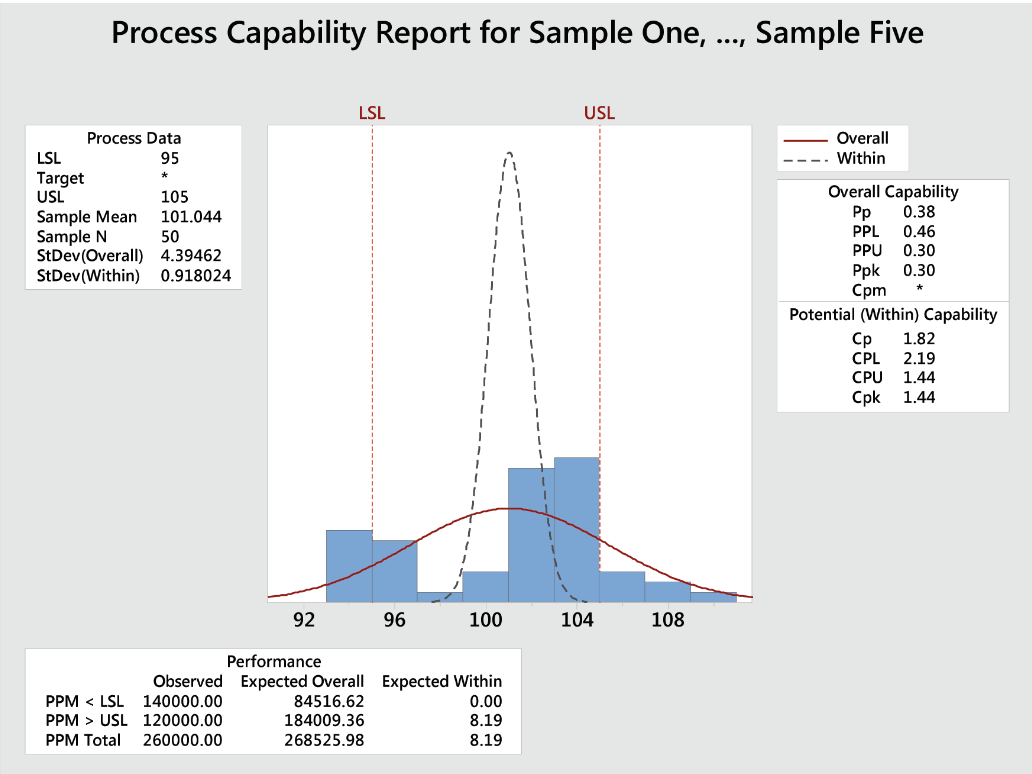

Figure 3: Process Capability Analysis of All Data

The 30,000-Foot-Level View

Which of the two control charting techniques is most appropriate? It depends on how one categorizes the source of variability relative to common and special causes. To explain this point, a manufacturing situation will be used, although the same thought process applies to transactional environments.

Let's consider that a new supplier's shipments are received daily and there is a difference between the shipments, which unknowingly affects the output of the process. To answer our original common versus special cause question, we need to decide if the impact of day-to-day differences on our process should be considered a component of common or special cause variability. If these day-to-day differences should be considered a process noise variable, a control charting procedure that considers the day-to-day variability as a source of common cause variability would be most appropriate.

For this to occur in the creation of a control chart, one needs a sampling plan where the impact from this type of noise variable occurs between subgroupings. I refer to the sampling plan that accomplishes this need *infrequent sampling/sub-grouping* and this high-level process-output perspective the 30,000-foot-level view. When creating time-series control charts at the 30,000-foot-level[3], one needs to include between-subgroup variability within the control chart limit calculations, as was achieved in the earlier *XmR* charting procedure.

One needs to highlight that a 30,000-foot-level objective is different from the original intent of control charts. In my opinion, a primary intent for traditional control charts is that the tool was used to timely identify unusual events that violated the mathematical properties inherent within the chart calculations. When this situation occurred, the observation was termed an assignable cause and action was to be taken to address the condition, if appropriate, in a timely fashion. A 30,000-foot-level chart to provide a high-level view of a process that assess both process stability and, when only common-causes variability currently exists (e.g., since the staging of a control chart because a process change occurred), provides a prediction statement.

30,000-foot-level Charts with Subgrouping

One would like to have flexibility to use a methodology that has infrequent sampling or subgrouping with multiple samples for each reported time interval but still addresses between-subgroup variability when calculating individuals-chart limits. For this situation, one can track the subgroup mean and log standard deviation using two individuals control charts to assess whether the process is stable/predictable. The reason that a log transformation (i.e., Box-Cox transformation lambda equals zero) can be needed for the standard deviation plot is that standard deviation is bounded by zero and a log transformation of standard deviation tends to follow a normal distribution.

For in-control or predictable processes, the original data is then used in a 30,000-foot-level report-out to determine the overall process capability and performance; e.g., percent non-conformance.

One point that should be highlighted is that a moving range chart (in an *XmR* pair of charts) only tracks the differences in adjacent-responses over time, which can also be observed in the corresponding individuals chart. Because of this and to make the chart-output response simpler to read, the moving range chart is not included in a 30,000-foot-level report out's individuals chart.

For the data in Table 1, Figure 4 shows a 30,000-foot-level report-out.

Rather than report process capability indices such as C_p, C_{pk}, P_p and P_{pk}, a 30,000-foot-level report-out provides a percentage non-conformance estimate whenever a specification is provided (See Figure 4). This value is determined from a probability plot and should be automatically reported at the bottom of the chart. A 30,000-foot-level process performance statement is easier to understand and is similar to a process expected overall performance report-out from a process capability analysis; i.e., 268,525.98 from Figure 3 is similar to a 26.852% nonconformance rate in Figure 4. In addition, if no specification exists, a 30,000-foot-level report-out would provide a best estimate for the process median and 80% frequency of occurrence.

One should also note from Figure 4 how a 30,000-foot-level report-out provides an estimate of how this stable process is not only performing now but in the future unless something were to change. If this prediction is undesirable, the 30,000-foot-level metric

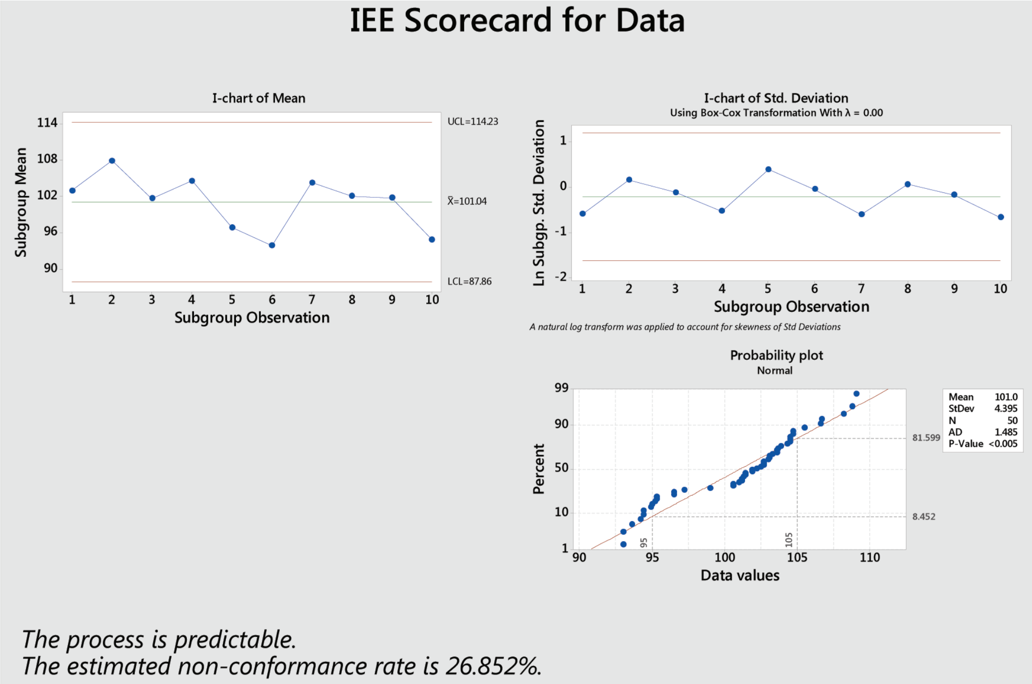

Figure 4: 30,000-foot-level Report-out

enhancement need pulls for a process improvement effort to enhance the process-output performance. One infers that a process was improved if the 30,000-foot-level individuals chart transitions to an enhanced level of performance.

Cost of Doing Nothing Differently

To determine if a process should be improved, one could calculate the cost of poor quality (COPQ) or the cost of doing nothing different (CODND). If the COPQ/CODND amounts are unsatisfactory, this metric improvement need should pull (used as a lean term) for creating a Lean Six Sigma project or other process improvement effort.

With this overall approach for metric reporting, an entire enterprise set of metrics could be collectively evaluated to determine where it is most beneficial to give focused improvement efforts. This differs from the use of Figure 1, which could lead one to create activities that are unproductive if one is attempting to understand the cause of isolated events, which are really common cause; i.e., firefighting common-cause (i.e., variability that occur between subgroups) issues as though they were special cause.

Applications

Metrics drive behavior; however, one needs to insure that not only the applicable metrics are tracked but that the report-out format for the measurements lead to the most appropriate behaviors. The 30,000-foot-level individuals chart(s) and corresponding capability/performance report-out (*in one chart*) provide a high-level view of process output, which is different from the application of traditional control charting. From an elevated organizational-performance-tracking view point, common cause process variability can be separated from special cause conditions. From this separation viewpoint, the most appropriate action can occur for a given set of conditions.

The 30,000-foot-level process-output tracking system can be used for:

- Baselining the output response from a process, which is to be improved
- Identification that an enhancement has been made to a process from a targeted improvement effort; i.e., a process shift would be staged in the 30,000-foot-level individuals chart and the prediction statement be made using the data that was present after the staging point

- Visual process control mechanism for maintaining the gain from an improved process
- An alternative to traditional organizational performance-metric reporting that addresses the issues described in a one-minute performance-scorecard reporting video[4]
- An alternative to red-yellow-green stoplight reporting and a table of numbers report-outs as described in a 15-minute video[5]. Traditional scorecards don't typically report-out performance metrics from a process point of view, which can lead to unhealthy, if not destructive behaviors; a 30,000-foot-level report-out overcomes these issues.
- An alternative to various scorecard report-outs (eight example illustrations are shown in the reference)[5]
- The structured reporting of performance metrics in an Integrated Enterprise Excellence (IEE) operational excellence system[6] with an alignment to the processes that created them through an organizational value chain

The 30,000-foot-level reporting format has application to a variety of process-output tracking situations:

- Continuous data: Subgroups (illustrated in this paper)
- Continuous data: No subgroup
- Attribute non-conformance rate data
- Attribute count data
- Non-normal data
- Seasonal data

Creation procedures for 30,000-foot-level report-outs is described for a variety of situations in chapters 12 and 13 of *Integrated Enterprise Excellence Volume III*[7].

How to Easily Create a 30,000-foot-level Chart

A Minitab add-in for the easy creation of 30,000-foot-level report-outs can be downloaded at no charge[8].

Organizations benefit when they link 30,000-foot-level performance metrics with the processes that created them. This objective can be achieved through an Integrated Enterprise Excellence (IEE) value chain. Additional benefits can be achieved when software is used so that 30,000-foot-level metrics are automatically updated and become clickable[9] to those in management and others who have an Internet connection and access authorization.

References

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3. Breyfogle, F. W., *Integrated Enterprise Excellence Volume III, Improvement Project Execution: A Management and Black Belt Guide for Going Beyond Lean Six Sigma and the Balanced Scorecard*, Citius Publishing, 2008, Example 12.2, pages 303-307.
4. One-minute video describing issues and resolution to traditional scorecard reporting: www.ieesystem.com.
5. Fifteen minute video describing issues with traditional red-yellow-green scorecard reporting and 30,000-foot-level alternative, also application of this reporting format to eight example scorecard report-outs http://www.ieesystem.com/scorecard-examples/.
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