P-Chart: Issues and Resolution

By Forrest W. Breyfogle III

P-charts are used in quality control to identify when special-cause or out-of-control conditions occur in time-series data so that timely corrective actions can be taken to resolve problems. Sometimes data from a p-chart are used also to provide a process capability statement or non-conformance statement.

However, there are issues in how p-charts are often created and applied.

The application shortcoming of p-charts will be described in this article along with an alternative 30,000-foot-level charting methodology that not only addresses this issue but also enhances application of the techniques. The described methodology not only improves the accuracy of common-cause and special-cause statements but also provides a better and more easily- understandable process capability or a process performance statement that is predictive.

This article will build on the special-cause and common-cause variability concepts described in the article Control Charting Issues: 30,000-foot-level Chart Resolution as it relates to *time-series attribute data compiled in subgroups.*

Traditional Control Charting

When examining time-series data, what we want to occur is the most appropriate action or non-action. However, the conclusion of what action or non-action to take can be a function of how the data are examined. This point will be illustrated using the data in Table 1[1], which provides the number of daily non-conformances that occur from the number of daily transactions that occur; i.e., 10,000.

These data could describe the number of daily non-conformances from an insurance company, hospital, or one-shift manufacturing facility.

Traditionally, proportion (p) non-conformance rates are tracked over time using a p chart to detect special-cause occurrences. This approach would be appropriate using a Shewhart strategy.

Whenever a measurement is beyond the LCL or UCL on a control chart, the process is said to be out of control. Out- of-control conditions are special-cause conditions, which can trigger causal problem investigations.

For the p chart of these data, shown in Figure 1, many causal investigations could have been initiated because there are many out-of-control signals. Out-of-control processes are not predictable; hence, no process capability claim should be made.

For p charts, failure rate p is tracked over time with an LCL and UCL of:

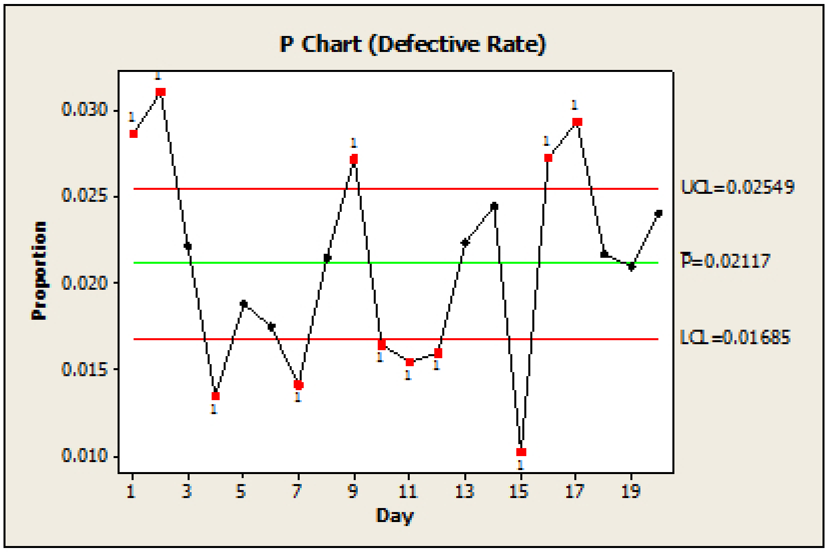
$$\text{LCL} = \bar{p} - 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \qquad \text{UCL} = \bar{p} + 3\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

From these equations, the LCL and UCL are determined using the average non-conformance rate ($\bar{p}$) and subgroup size (n). When the subgroup size is large, as it can be in many business situations, the distance between the LCL and UCL can become quite small. Variability from day-to-day material lot differences or day-to-day transaction differences can create the type of out-of-control signals shown in Figure 1.

Day	Non-conformances	Subgroup size	Non-conformance rate
1	287	10,000	0.0287
2	311	10,000	0.0311
3	222	10,000	0.0222
4	135	10,000	0.0135
5	188	10,000	0.0188
6	175	10,000	0.0175
7	142	10,000	0.0142
8	215	10,000	0.0215
9	272	10,000	0.0272
10	165	10,000	0.0165
11	155	10,000	0.0155
12	160	10,000	0.0160
13	224	10,000	0.0224
14	245	10,000	0.0245
15	103	10,000	0.0103
16	273	10,000	0.0273
17	294	10,000	0.0294
18	217	10,000	0.0217
19	210	10,000	0.0210
20	241	10,000	0.0241

From Table 13.1, *Integrated Enterprise Excellence Volume III - Improvement Project Execution: A Management and Black Belt Guide for Going Beyond Lean Six Sigma and the Balanced Scorecard*, Forrest W. Breyfogle III, Bridgeway Books/Citius Publishing, Austin, TX, 2008.

Table 1: Time-Series Data from Process



Modified from Table 12.1, *Integrated Enterprise Excellence Volume III - Improvement Project Execution: A Management and Black Belt Guide for Going Beyond Lean Six Sigma and the Balanced Scorecard,* Forrest W. Breyfogle III, Bridgeway Books/Citius Publishing, Austin, TX, 2008.

Figure 1: Traditional *p* Chart of Defective Rate

30,000-foot-level Charting

An individuals (*X*) chart tracks an individual value over time where the chartôs control chart limits consider between-subgroup variability. When adjacent subgroups are used to determine average moving range ($\overline{MR}$), the *X* chart has a LCL and UCL of:

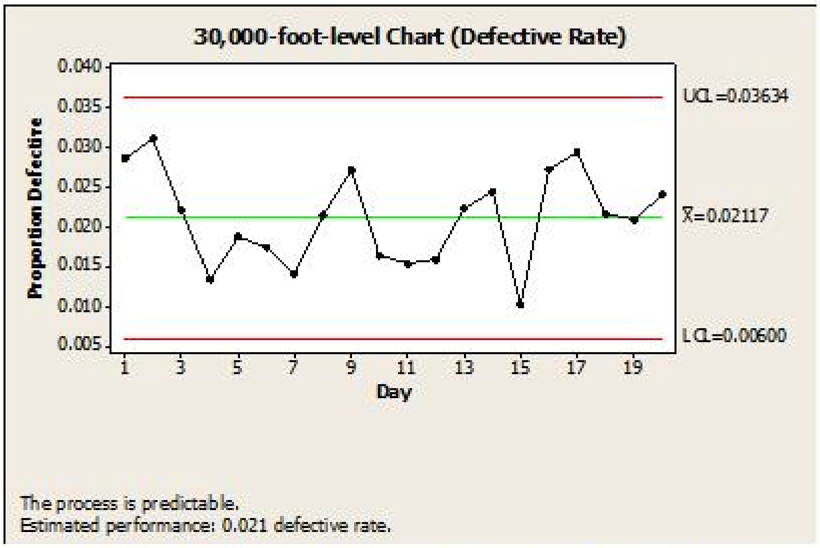
$$\text{LCL} = \bar{x} - 2.66(\overline{\text{MR}}) \qquad \text{UCL} = \bar{x} + 2.66(\overline{\text{MR}})$$

Unlike with a p-chart, the control limits for an individuals or *X* chart are a function of the average moving range between adjacent subgroups. The importance of capturing between-subgroup variability when calculating statistical process control-chart upper and lower control limits was discussed in Control Chart Issues: 30,000-foot-level Chart Resolution.

The *X* chart is not robust to non-normal data; therefore, for some situations, data need to be transformed when creating the control chart. One example of a non-normal condition is when there is or tends to be a natural boundary condition. For this situation, the control chart can cause false signals where common-cause variability appears as to be special cause.

When attribute control-chart subgroup sizes are similar, an *X* chart can often be used in lieu of a *p* chart when creating a 30,000-foot-level chart. The advantage of this approach is that between-subgroup variability will impact control-chart limit calculations. An *X* chart of the non-conformance rate in Table 1 is shown in Figure 2.

This *X* chart indicates the process is in control and is quite different from the conclusion drawn from the control chart in Figure 1. When a process is in control, it can also be said to be predictable. When a process is in control/predictable, we can not only make a statement about the past but also use historical data to make a statement about what we might expect in the future, assuming things stay the same.



Modified from Figure 13.4, *Integrated Enterprise Excellence Volume III - Improvement Project Execution: A Management and Black Belt Guide for Going Beyond Lean Six Sigma and the Balanced Scorecard*, Forrest W. Breyfogle III, Bridgeway Books/Citius Publishing, Austin, TX, 2008.

Figure 2: 30,000-foot-level Chart of Non-conformance Rate[5]

The process capability/performance metric for this process can then be said to have a non-compliance rate about 0.021. That is, since the process is in control/predictable, it is estimated that the future non-conformance rate will be about 0.021, unless a significant change is made to the process or something else happens that either positively or negatively affects the overall response. This situation also implies that Band-Aid or firefighting efforts can waste resources when fundamental business process improvements are really what are needed.

If improvement is needed for this 30,000-foot-level metric, a Pareto chart of defect reasons can give insight to where improvement efforts should focus. The most frequent defect type could be the focus of a new Lean Six Sigma project. For this Lean Six Sigma implementation strategy, I could say common-cause measurement improvement needs are pulling for the creation of a Lean Six Sigma project.

A subtle, but important, distinction between the two approaches is the customer view of the process. In the example above, the Shewhart approach (*p* chart) encourages a firefighting response for each instance outside the control limits, while the Integrate Enterprise Excellence (IEE) approach encourages looking at the issue as an organic whole - an issue of capability rather than stability. If the problem is an ongoing one, the IEE view is more aligned with the customer view (whether internal or external) of process performance. The process is stable, though perhaps not satisfactory, from the customer perspective.

Pulling for the Creation of Projects

The selection of projects within Lean Six Sigma is critical. However, organizations often work on projects that may not be important to the overall business. With this procedure, organizations could even be sub-optimizing processes to the detriment of the overall enterprise.

Business existence and excellence (E) depend on more customers and cash (MC^2). The IEE system focuses on $E = MC^2$ for project selection.

Within IEE, operational high-level metrics at the enterprise level pull (used as a Lean term) for the creation of projects. These projects can then follow a refined define-measure-analyze-improve-control (DMAIC) roadmap4 that includes Lean tools for process improvement or a define-measure-analyze-design-verify (DMADV) roadmap for product or process design needs.

Summary

For the presented data, the 30,000-foot-level report-out changed how one would view the processô performance from considering that the process was not stable using a traditional *p*-chart approach to a process that has a non-compliance rate of about 2.1%, when assessing the process at the 30,000-foot-level. This approximate unacceptability rate can be expected in the future unless something changes. To improve a processô common-cause level of performance when reported at the 30,000-foot-level, the process needs to be enhanced; e.g., through a Lean Six Sigma improvement project.

30,000-foot-level Charting Applications

The described 30,000-foot-level charting technique has many applications, as described in 30,000-foot-level Performance Reporting Applications

References

1. Walter A. Shewhart, *Economic Control of Quality of Manufactured Product*, ASQ Quality Press, 1931, reprinted in 1980.
2. Western Electric, *Statistical Quality Control Handbook*, Western Electric Co., 1956.
3. W. Edwards Deming, *Out of the Crisis*, MIT Press, 1986.
4. Forrest W. Breyfogle III, *Integrated Enterprise Excellence Volume III - Improvement Project Execution: A Management and Black Belt Guide for Going Beyond Lean Six Sigma and the Balanced Scorecard*, Bridgeway Books/Citius Publishing, 2008
5. Figure created using Enterprise Performance Reporting System (EPRS) Software

About the Author
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In a professional career spanning over a quarter century, Forrest Breyfogle has established himself as a leading edge thinker, a prolific author, an innovative consultant, a world-class educator, and a successful business executive. His work is documented in eleven books and over ninety articles on the topic of quality improvement.

A professional engineer, Forrest is also a member of the board of advisors for the University of Texas Center for Performance Excellence. He is the founder and CEO of Smarter Solutions, Inc., an Austin, Texas based consulting firm offering business measurement and improvement consultation and education to a distinguished list of clients worldwide, including BAMA, CIGNA, Dell, HP, IBM, Oracle Packaging, Sherwin Williams, Cameron, TIMET, and TATA. He served his country on active duty in the US Army for 2 years, and has played an active leadership role in professional and educational organizations. Forrest received the prestigious Crosby Medal from the American Society for Quality (ASQ) in 2004 for his book, *Implementing Six Sigma* (second edition). This award is presented annually by the American Society for Quality to the individual who has authored a distinguished book contributing significantly to the extension of the philosophy and application of the principles, methods, or techniques of quality management. Mr. Breyfogle was named Quality Professional of the Year for 2011 by Quality Magazine and in 2012 was awarded alumni of the year by Missouri University of Science and Technology.

He is a widely recognized authority in the field of management improvement and is a frequent speaker before professional associations and businesses. His earlier work in the field of management science has been widely acclaimed. A previous book, *Implementing Six Sigma*, sold over 40,000 copies and still ranks among the top Amazon books in Applied Mathematics/Engineering Statistics and Industrial Engineering /Quality Control.

He founded Smarter Solutions in 1992 after a 24-year career at IBM. The associates of Smarter Solutions specialize in helping companies throughout the world improve their bottom line and customer satisfaction through the implementation of techniques that are beyond traditional Lean Six Sigma and the balanced scorecard methodologies. His latest and most extensive work has been in the documentation of a new system of enterprise management, the Integrated Enterprise Excellence (IEE) system, in a series of four books. IEE provides a detailed roadmap that builds on and integrates the best practices of earlier disciplines like Six Sigma, Lean, TQM , PDCA, DOE, and TPS combined with innovative analytical tools to produce improvements at the highest level of an enterprise.

In addition to assisting hundreds of major clients in the wise implementation of improvement systems worldwide, Forrest has also developed over 300 hours of classroom instruction used to train executives, managers, and Black Belt practitioners to plan for, implement, and manage IEE systems. He also leads formal seminars and workshops worldwide.

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