Control Charts for Monitoring Test Method Performance

By Polona K. Carson and Khalid S. Al-Ghamdi

Q Which control charts are used for monitoring test method performance?

A Control charts are efficient tools for monitoring test method performance and maintaining stability of test method bias and precision. Each data point plotted on the control chart reflects on the site performance of the laboratory measurement process, which includes written test procedures, testing equipment, consumables, reagents, analysts' skills, sample matrix and environment.

ASTM E2587, Practice for Use of Control Charts in Statistical Process Control, describes in detail the use of different types of control charts. The most known and commonly used control charts are Shewhart control charts (I/MR, Xbar/R or Xbar/S charts). They are capable of quickly detecting shifts in the testing process that are larger than 1.5 sigma, but they are not sensitive to smaller shifts. We can improve their effectiveness by using interpretation rules like the Western Electric rules (see ASTM E2587). However, we need to be careful when applying multiple interpretation rules because this will increase the rate of false positive signals.

Two other types of charts are designed to detect shifts in the process mean that are smaller than 1.5 sigma. These are the exponentially weighted moving average chart (EWMA) and the cumulative sum control chart (CUSUM). Shewhart control charts plot current subgroup statistics and do not retain any process history. Incorporating historical process behavior into each plotted point on the chart results in more power to detect small shifts. The EWMA and the CUSUM control charts are very effective when used as a companion to the chart of individual values (I chart).

The EWMA control chart plots exponentially weighted moving averages. This is a smoothing procedure that filters out process noise and amplifies small upsets in a process. This type of chart is suitable for detecting trending or drifting process mean.

The CUSUM control chart plots the cumulative sums of process deviation from a target value. Even a very small deviation from the target value will show on this chart as a steady increase or decrease in plotted values. Therefore, this chart is suitable for detecting test method bias when an accepted reference value for control material is available. The CUSUM control chart also determines the time of the first appearance of an assignable cause. A CUSUM chart can also be used to detect the departure of process outside of a defined tolerance band. This can be used as a tool to determine schedule for preventive maintenance of measurement system due to wear in parts of equipment, deterioration of reagents, validity of calibration, etc. Because CUSUM control charts have many valuable applications for monitoring test method performance, they will be added to the next revision of ASTM E2587.

CHARTS FOR MONITORING TEST METHOD PERFORMANCE

It is important to carefully plan which control charts to implement as a monitoring tool for each test method. Whether the upset in a measurement system is large or small, it can have serious consequences for the laboratory if not detected in a timely manner. Because large perturbations in a measurement process can be catastrophic for data quality, the first priority is to detect them as quickly as possible. Therefore, a Shewhart control chart is always needed. The following procedure can be then used to decide whether a companion time-weighted control chart is needed, and if so, which one(s):

— Define the smallest change in process mean (Δ) that needs to be detected quickly;
— Based on historical data, estimate the largest reasonable measurement process variation s;
— Compute the relative size of shift to be detected: $k = \Delta / s$;
— If $k >= 1.5$, a Shewhart chart (I/MR, Xbar/R or Xbar/S) is sufficient;
— If $k < 1.5$, use a time-weighted chart (EWMA, CUSUM) as a companion control chart.

Using an EWMA or a CUSUM chart to detect and correct small process shifts is a good strategy to minimize large process upsets. Whether to use the EWMA or the CUSUM chart depends on the context of the testing process and laboratory risk management practice. When implementing a chart as a tool to either identify test method bias or to develop a maintenance schedule, the CUSUM is a better choice because it plots deviations from a predefined target value.

A PRACTICAL EXAMPLE

Boiling range characteristics of refinery products are determined by distillation at atmospheric pressure (ASTM standard test method D86). Weekly control samples are tested to monitor performance of the laboratory measurement process. Results for 55 control samples of the same control material obtained on one instrument are plotted on an I chart (Fig. 1). There are no signals indicating large upsets of the process, but there are 11 consecutive points below the center line (samples 40 to 50), indicating a possible shift in process mean value.

The EWMA chart (Fig. 1) with smoothing parameter λ = 0.1 is designed to quickly detect shift in mean value of 1 to 1.5 sigma. This chart clearly shows a downward process trend. Five of the control points beginning at sample 45 indicate change in the process mean.

A CUSUM chart can be designed to have similar detection capabilities as the EWMA chart. However, CUSUM charts have another valuable function; they can be used as a tool to detect the deviation from a specified target value. To demonstrate the power of this CUSUM capability we assume that the target value (ARV) is 493.8 °F (256.6 °C), a value of 0.5 process standard deviations below the process mean. The CUSUM chart (Fig. 1) has two sets of points. Blue dots depict the CUSUM for deviations above the target value, and green dots depict the CUSUM for deviations below the target value. Similar to the EWMA chart, the CUSUM chart shows the downward trend in process mean. Red signals on the blue upper CUSUM line at samples 8, 13, 54 and 55 indicate deviation from ARV and resulting bias of the measurement process. This example shows how sensitive the CUSUM is to small departures of process from a target value.

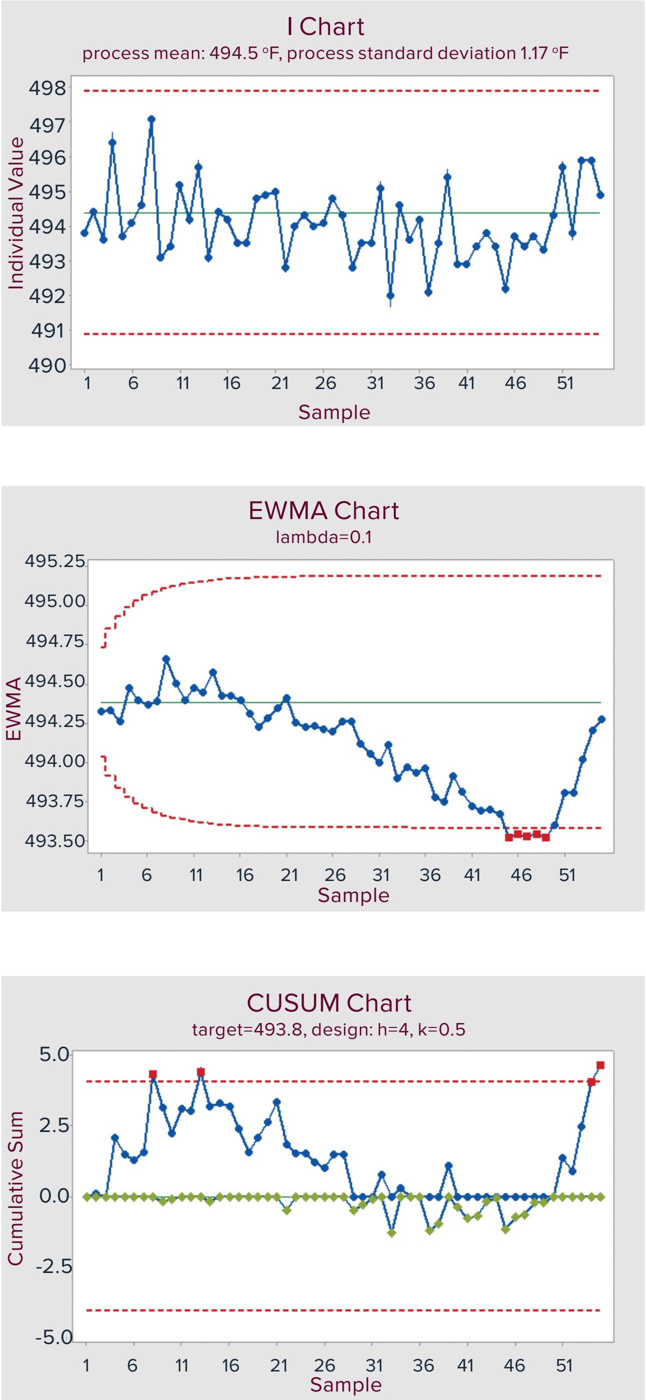
By using a combination of Shewhart and time-weighted control charts we are able to efficiently monitor test method bias and precision.

Polona K. Carson, Ph.D., P&J Carson Consulting LLC, Ohio, is secretary of Committee E11 on Quality and Statistics and a member of Committee D02 on Petroleum Products, Liquid Fuels and Lubricants.

Khalid S. Al-Ghamdi, Saudi Aramco, Saudi Arabia, is a member of Committees E11 on Quality and Statistics and D19 on Water.

John Carson, Ph.D., of CB&I Federal Services LLC and P&J Carson Consulting LLC, Ohio, is the Data Points column coordinator. Vice chairman of E11.30 on Statistical Quality Control, part of E11 on Quality and Statistics, he is also a member of Committees E50 on Environmental Assessment, Risk Management and Corrective Action and of D02 on Petroleum Products, Liquid Fuels and Lubricants.

Figure 1 — I, EWMA and CUSUM Charts for Petroleum Distillate Temperature



Send your statistics questions to Maryann Gorman at mgorman@astm.org.