

Control Chart Selection: Matching the Chart to the Data

Variables charts, attributes charts, and time-weighted charts. A decision tree for selecting the right chart based on data type, subgroup size, and detection objective. Rational subgrouping—the most important and most misunderstood concept in SPC.

Ref: Western Electric Handbook · Nelson (1984) · Montgomery Ch. 5–9 · AIAG SPC Manual

I — Publication

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Author Eric Wolters

Reading 16 min

SPC · Charts

II — Variables Charts

I-MR (Individuals and Moving Range)

The I-MR chart is for continuous data with subgroup size $n = 1$. Each observation is plotted individually on the I chart; the range between consecutive observations is plotted on the MR chart. Use I-MR when: measurements are expensive or destructive (one part per batch), when every unit is measured but there is no logical basis for forming subgroups, or when the production rate is slow enough that subgrouping would span days.

The I-MR chart is the most commonly used and most commonly misapplied control chart. It assumes the underlying data are approximately normal. For non-normal data, the control limits are incorrect and the false alarm rate changes. The I chart is also less sensitive to small shifts than subgroup-based charts because it has no averaging effect. For detecting a 1-sigma shift, the I-MR chart has an average run length (ARL) of approximately 44 subgroups. The X-bar chart with $n = 5$ detects the same shift in about 6 subgroups.

X-bar/R and X-bar/S

When rational subgroups of size 2-9 exist, use X-bar/R. The subgroup mean is plotted on the X-bar chart; the within-subgroup range is plotted on the R chart. The averaging within subgroups makes the X-bar chart more sensitive to process shifts and more robust to non-normality (by the Central Limit Theorem).

For subgroup sizes of 10 or more, replace the R chart with the S chart (plotting the subgroup standard deviation). The range becomes an inefficient estimator of dispersion for large subgroups. The S chart uses all observations within the subgroup, not just the maximum and minimum.

Rational Subgrouping

A rational subgroup is a set of observations that were produced under essentially the same conditions. The within-subgroup variation estimates the common-cause, short-term noise. The between-subgroup variation captures everything else. The power of the control chart to detect shifts depends entirely on how well the subgrouping separates common cause from special cause.

If parts within a subgroup come from the same cavity, same operator, same material batch, and are measured within minutes of each other, the within-subgroup variation is small. The control limits are tight. Any shift in the process mean—from a tool change, material lot change, or setup adjustment—produces a signal on the chart. This is a good rational subgroup.

If parts within a subgroup are drawn from the day's output—different cavities, different operators, different hours—the within-subgroup variation includes all those sources. The control limits are wide. Process shifts hide within the inflated limits. The chart is insensitive. This is a bad rational subgroup.

III — Attributes Charts

Binomial Charts: p and np

The **p chart** tracks the proportion nonconforming in each subgroup. It handles variable subgroup sizes. The **np chart** tracks the count of nonconforming items and requires constant subgroup size. Both assume each item is independently classified as conforming or nonconforming, with a constant probability of nonconformance.

The minimum subgroup size for an attributes chart depends on the defect rate. The chart needs enough nonconforming items per subgroup to detect changes. A rule of thumb: $n\bar{p}$ (the average number of defectives per subgroup) should be at least 5. If your defect rate is 1%, you need subgroups of at least 500. Many implementations violate this, producing charts with a lower control limit of zero and no ability to detect improvement.

Poisson Charts: c and u

The **c chart** counts defects (not defectives) per inspection unit. The **u chart** counts defects per unit and handles variable inspection areas or sample sizes. Both assume defects occur independently at a constant rate—the Poisson model.

Use c/u charts when: counting scratches per panel, solder defects per board, contamination particles per wafer, or any situation where multiple nonconformities can occur on a single unit. The distinction between defects (c/u) and defectives (p/np) is fundamental: a unit with 3 scratches is one defective but three defects.

The Constant Subgroup Size Trap

The np and c charts require constant subgroup size. If your inspection lot size varies (which it usually does), use the p or u chart instead. Alternatively, standardize the charted statistic. Do not force the data into a constant-size chart by discarding observations or padding subgroups. This introduces bias or destroys the chart's statistical properties.

IV — Time-Weighted Charts

CUSUM (Cumulative Sum)

The CUSUM chart accumulates deviations from the target value. Small, sustained shifts that the Shewhart chart misses for dozens of subgroups produce a clear trend on the CUSUM. A tabular CUSUM with decision interval $h = 5$ and reference value $k = 0.5$ detects a 1-sigma shift with an ARL of approximately 10—compared to 44 for the I chart and 6 for the X-bar chart with $n = 5$.

The CUSUM is optimal for detecting sustained shifts of a known size. It is less effective for detecting large, sudden shifts (where Shewhart excels) and for shifts of unknown magnitude.

EWMA (Exponentially Weighted Moving Average)

The EWMA chart applies exponentially decreasing weights to past observations. The smoothing parameter λ controls the memory: small λ (0.05-0.10) gives long memory and high sensitivity to small shifts; large λ (0.25-0.40) gives short memory and behavior approaching the Shewhart chart. The EWMA is robust to non-normality and handles individual observations well.

When Shewhart Is Not Enough

Use CUSUM or EWMA when the process must detect shifts smaller than 1.5 sigma, when the economic cost of delayed detection justifies the additional complexity, or when the process naturally drifts and needs continuous monitoring rather than alarm-based detection. In chemical processes, pharmaceutical manufacturing, and semiconductor fabrication, small sustained shifts are the dominant failure mode, and time-weighted charts are standard practice.

V — Nelson Rules

The Eight Rules

Nelson (1984) codified eight run rules that detect non-random patterns on Shewhart charts. Rule 1 (point beyond 3-sigma) is the standard Shewhart test. Rules 2-8 detect runs, trends, oscillations, and stratification that indicate assignable causes even when no point exceeds the limits.

Rule 1: One point beyond zone A (3-sigma). False alarm rate: 0.27% per point. **Rule 2:** Nine consecutive points on the same side of the center line. Detects sustained shifts. False alarm rate: 0.39% per set of 9. **Rule 3:** Six consecutive points steadily increasing or decreasing. Detects trends (tool wear, drift). **Rule 4:** Fourteen consecutive points alternating up and down. Detects oscillation (overcorrection, two-stream mixing).

Rules 5-8 involve the zone structure (zones A, B, C at 1, 2, 3 sigma) and detect various patterns of excessive or insufficient variation relative to the expected normal distribution.

Which Rules to Enable

Enabling all eight rules simultaneously increases the overall false alarm rate. With all rules active, the probability of at least one false alarm per 100 points is substantial—high enough to cause alarm fatigue. The AIAG SPC manual recommends Rule 1 plus selected supplementary rules based on the process. A practical default is Rules 1, 2, and 3: beyond limits, long runs, and trends. Add Rule 4 if overcorrection is a known failure mode. Add the zone rules only if the process is well-behaved enough that the additional false alarms are tolerable.

VI — Decision Tree

Chart Selection Flowchart

Start with the data type. **Continuous (variables) data:** Is the subgroup size 1? Use I-MR. Subgroup size 2-9? Use X-bar/R. Subgroup size 10+? Use X-bar/S. Need to detect small sustained shifts? Add CUSUM or EWMA.

Attribute data: Are you counting defectives (pass/fail per unit) or defects (counts per unit)? Defectives with constant subgroup size: np. Defectives with variable subgroup size: p. Defects with constant inspection unit: c. Defects with variable inspection unit: u.

Detection objective: Large, sudden shifts (1.5 sigma or more): Shewhart charts are sufficient and simple. Small, sustained shifts (0.5-1.0 sigma): CUSUM or EWMA. Monitoring for drift in a highly capable process: EWMA with small λ .

The [control chart generator](#) implements all chart types with automatic limit calculation and configurable Nelson rules.

VII — Rational Subgrouping

What "Rational" Actually Means

Shewhart's principle: "A subgroup should be selected so that the chance of assignable causes occurring *between* subgroups is maximized, and the chance of assignable causes occurring *within* subgroups is minimized." This is the design criterion. Everything else follows from it.

Common Subgrouping Mistakes

Subgrouping by convenience: Collecting 5 consecutive parts every hour because it fits the operator's schedule. If the process shifts within the hour (tool offset, material change), the shift occurs within the subgroup and inflates the within-subgroup variation. The chart becomes insensitive.

Mixing process streams: A 4-cavity mold produces parts from all cavities simultaneously. If each subgroup contains one part from each cavity, the cavity-to-cavity differences appear as within-subgroup variation. The chart cannot detect a single cavity drifting because the other three dilute the signal. Chart each cavity separately, or use a between/within analysis to decompose the variation.

Beautiful but useless charts: When the subgrouping is wrong, the chart can look perfectly in control while the process produces nonconforming product. The within-subgroup variation is artificially large, the control limits are wide, and real signals disappear into the noise. A chart that never triggers an alarm is not necessarily a good chart—it may be a chart that cannot see.

Before constructing any control chart, define the rational subgroup. Document what is held constant within the subgroup and what is allowed to vary between subgroups. If the chart shows no signals despite known process problems, the subgrouping is the first thing to question.

VIII — Related Instruments

INSTRUMENT	SPECIFICATION
Control Chart Generator	I-MR, X-bar/R, X-bar/S, p, c, u, CUSUM, EWMA with Nelson rules.
Cpk / Ppk Calculator	Capability analysis after process stability is confirmed.
Sample Size Calculator	Subgroup size for desired ARL performance.

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