

INTEGRATING STATGRAPHICS INTO A SIX SIGMA PROGRAM

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Introduction

This white paper discusses how integrating the STATGRAPHICS *Plus* statistical tools into a Six Sigma program can provide ongoing benefits across an enterprise. Starting with a brief overview of the Six Sigma philosophy, the discussion then focuses on how the analytical and reporting tools within the STATGRAPHICS *Plus* software can be used to implement key components of the Six Sigma approach.

What is the Six Sigma Philosophy?

The "Six Sigma" quality approach was pioneered in the 1980s by Motorola in response to a rising tide of global competition. Following a top-to-bottom analysis of its business operations, Motorola adopted a set of processes geared toward reducing the time required to take a product from concept to manufacture while simultaneously reducing the defects in products distributed to its customers.

Since then the Six Sigma approach has become a widely used management strategy for initiating a comprehensive review of all the processes a company undertakes to create, market, and support its products. A rule-of-thumb is that average processes operate at a three-sigma level; best-in-class at six sigma. Generally, the fundamental objective is that products and processes experience only 3.4 defects per million opportunities.

The benefits of a successful Six Sigma program are many: cost savings, productivity gains, improved production cycle times, reduction in errors, and elimination of unnecessary work. Better processes drive top-line growth, increase operating margins, and reduce working capital and spending.

Implementing Six Sigma

From the STATGRAPHICS *Plus* perspective, implementing a Six Sigma program means giving a company's employees the most powerful statistical tools available to achieve their goals. These tools should serve both as a guide for improving processes by identifying trends away from set quality standards and as an archive for storing process information for future reference.

A company committing itself to a Six Sigma quality program must put in place an intensive training program for key executives and staff. In turn, these people learn to (1) organize and effectively lead the deployment of the program, and (2) implement and use statistical tools in their business-improvement efforts.

The STATGRAPHICS Plus Statistical Toolkit

One goal for this white paper is to illustrate the impact that using STATGRAPHICS *Plus* can have within an organization. Six Sigma training involves teaching employees how key statistical tools are combined and sequenced to form a methodical and repeatable process for solving vital

manufacturing, engineering and administrative problems. These tools should help users gain a better understanding of descriptive statistics and the relationship between variables.

Since its development in the early 1980s, STATGRAPHICS *Plus* has concentrated on providing statistical tools that can be used both to (1) design quality into products, and (2) ensure that acceptable quality is maintained throughout the production process. This approach fits well with the broad Six Sigma mandate to develop an in-depth understanding of the philosophy as well as the theory, tactics, strategy, and application tools.

STATGRAPHICS *Plus* is one of the few available statistical software applications that is flexible enough to provide entry-level access for virtually everyone within a company, while still ensuring that high-level statistical algorithms are available for addressing complex issues and calculations. It is a statistical software package that will serve a range of users from machine operators and shop floor supervisors to design and process engineers.

To provide this wide latitude of functionality, STATGRAPHICS *Plus* incorporates a number of unique features:

StatWizard -- A tool to guide novice or casual users through the creation of an analysis from the selection of data to the choice of analytical options.

StatAdvisor -- A feature that provides short and easy-to-understand interpretations of all the reports and graphs in a statistical analysis.

StatFolios -- The main mechanism within STATGRAPHICS *Plus* for saving information about analyses and their related data. An alternative to a macro language, this dialog-box driven approach allows users to save a single analysis or a combination of analyses that can encompass the most complex calculations.

StatGallery -- A special tool for archival and report-generation purposes. Up to nine text and graphics panes can be arranged on a single page. An overlay feature allows users to create compound graphics. This is an ideal tool for comparing month-to-month or year-to-year data.

StatReporter -- A reporting tool that is accessible from within a STATGRAPHICS *Plus* session. Users can combine tables, graphs and their own notes into a personalized report. Using the Paste-Link feature, the StatReporter information updates whenever you update the linked analysis.

These features, plus others, embrace a new way of thinking about completing tasks quickly and efficiently. And they can be a powerful force in decision making or empowering employees.

The following sections provide explanations and examples of how various analyses support multiple aspects of the goals of a Six Sigma implementation: methods for monitoring, controlling, and improving a process through statistical analysis.

Measuring the Process

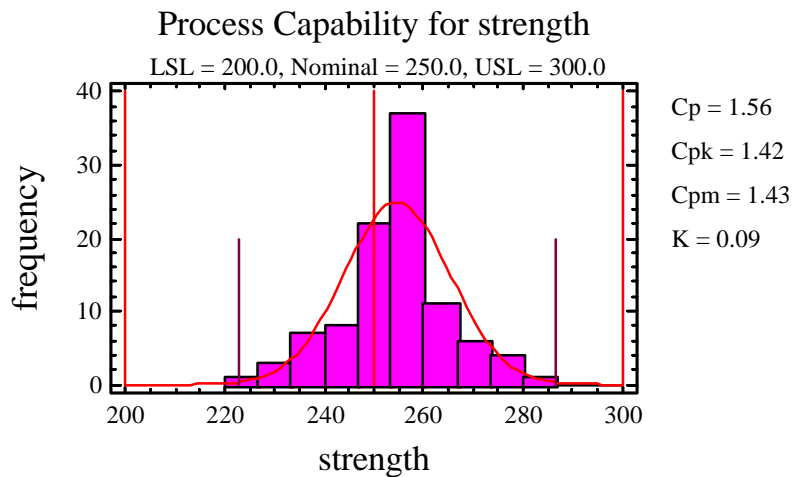
Most items manufactured today are produced using established specification limits, which ensure that a process is producing a quality product. The Process Capability Analysis, based on a sample of data, estimates the percentage of product that meets the specification limits and calculates various capability indices to summarize the conformance to *defects per million criteria*.

Because not all samples of data come from a normal distribution, STATGRAPHICS *Plus* includes several tests for normality. The analysis can be based on any of seven other probability distributions or it can calculate non-normal capability indices using a Pearson curve.

A Capability Plot is the best way to illustrate the analysis, which is shown in the figure below (illustrating a capable process). The Capability Plot compares the observed product performance with the established specifications by fitting a probability distribution to a sample of data and then by estimating various capability indices. The indices can be labeled as either Cp, Cpk, etc. or Pp, Ppk, etc. The fitted distribution provides estimates of the percentage of product that is out of specification over time.

A process capability study usually measures functional parameters on the product, not the process itself. When the process can be directly observed and the data collection controlled or monitored, the study is a true process capability study. By controlling the data collection and knowing the time sequence, conclusions can be made about the stability of the process over time.

Other tools useful in conducting a process-capability study are histograms or probability plots, control charts, and designed experiments, all available in STATGRAPHICS *Plus*.



```

Data variable: strength

Distribution: Normal
  sample size = 100
  mean = 254.64
  standard deviation = 10.6823

6.0 Sigma Limits
  +3.0 sigma = 286.687
  mean = 254.64
  -3.0 sigma = 222.593
  
```

Specifications	Observed Beyond Spec.	Z-Score	Estimated Beyond Spec.	Defects Per Million
USL = 300.0	0.000000%	4.25	0.001087%	10.87
Nominal = 250.0				
LSL = 200.0	0.000000%	-5.12	0.000016%	0.16
Total	0.000000%		0.001103%	11.03

The above table shows a process that is operating somewhat above the Six Sigma target of 3.4 defects per million. If the process can be re-centered so the upper Z-score rises above 4.5, that goal will be achieved.

Statistical Tolerance Limits

It is often necessary to use information from a process capability study to set specifications for discrete parts or components that interact with other components to form the final product. Engineers want to know what type of limits can be achieved from a given sample of data. Statistical tolerance limits show the estimated interval within which a specified percentage of product lies. Comparing these limits to the specification limits indicates the amount of improvement needed in the process.

```
Normal Tolerance Limits for strength

Normal distribution
  Sample size = 100
  Mean = 254.64
  Sigma = 10.6823

Specifications
  USL = 300.0
  Nominal = 250.0
  LSL = 200.0

95.0% tolerance interval for 99.9997% of the population
  Xbar +/- 5.13114 sigma
  Upper: 309.452
  Lower: 199.828
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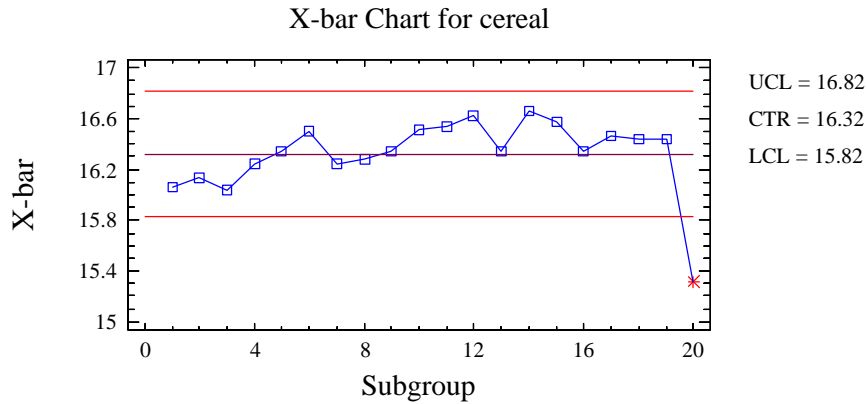
Control Charts

Manufacturers know that it is impossible to inspect or test quality into a product; the product must be built right the first time. The manufacturing processes must be stable and all the individuals involved in the process must continuously try to improve the performance of the process and reduce variability. Control charts are the simplest and easiest way to do this.

A typical control chart is a plot of statistics calculated from data samples taken from a process versus time. A centerline and one or two control limits are used to signal out-of-control behavior. STATGRAPHICS *Plus* distinguishes between two important scenarios: *initial studies* used to determine if the process is in a state of statistical control without specifying any target values for the process, and *control-to-standard studies* used to determine if the process is consistent with previously observed or desired behavior by plotting the data against pre-established control limits.

Variables control charts are used to analyze measurement data and include X-bar and R charts, X-bar and S charts, X-bar and S-Squared charts, and individuals charts used to analyze data when only one item is sampled.

Attributes control charts are used to analyze items classified according to features that cannot be measured and include the *p* Chart, *np* Chart, *u* Chart, and *c* Chart.



For situations when a process shifts only a small amount from its usual level, STATGRAPHICS *Plus* provides *time-weighted control charts* that take into account the past history of the process when determining if a process is out of control. Time-weighted control charts include the Moving Average Chart, EWMA Chart, CuSum Chart (V-mask and H-K), as well as individuals charts for each of the above.

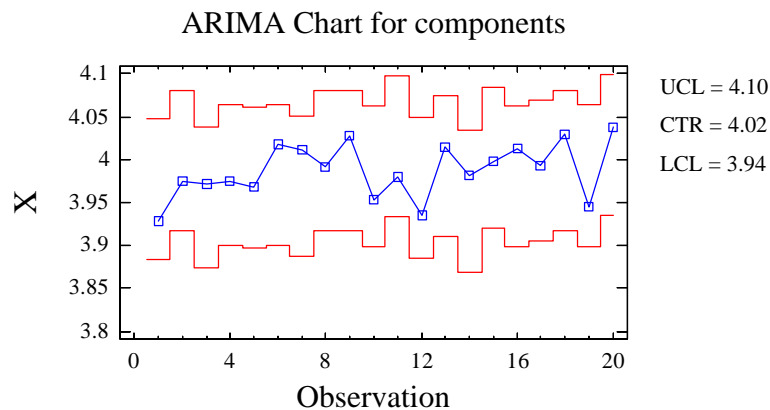
STATGRAPHICS *Plus* allows various enhancements to be made to all of its control charts. For example, warning limits can be added for an early signal that drifts are occurring in a process, or moving-average smoothers can be added to estimate underlying trends.

Special Purpose Control Charts

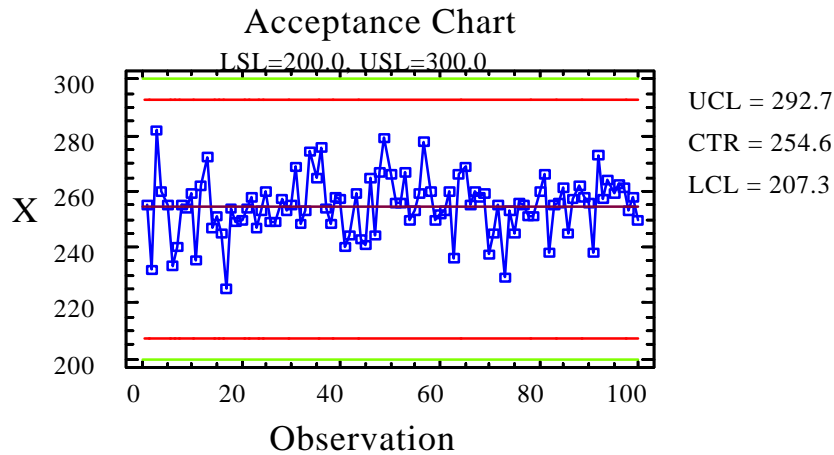
When control charts are used to determine the acceptance or rejection of a product, both specification limits and modified control limits may be needed to maintain the desired manufacturer and consumer quality metrics.

STATGRAPHICS *Plus* contains three special-purpose charts: ARIMA, Toolwear, and Acceptance control charts. Two versions of each chart are available, one for situations that measure more than one item at each time period and another for individuals data.

For example, moving control limits may aid in steering the process in the proper direction:



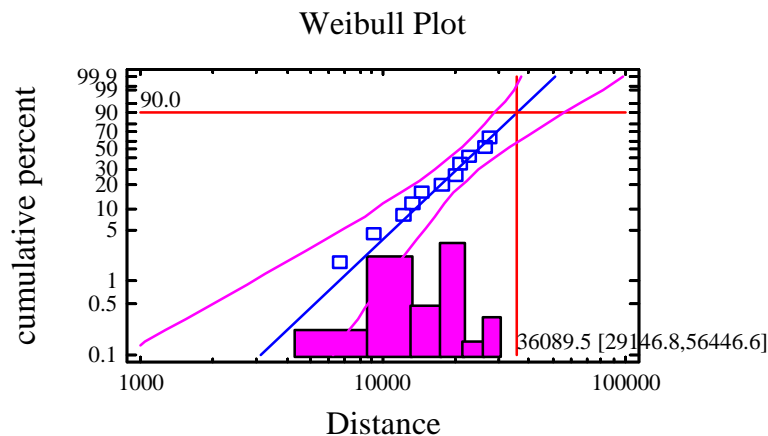
When control charts are used to determine acceptance or rejection of a product, both specification limits and modified control limits may be needed to maintain desired producer's and consumer's risks:



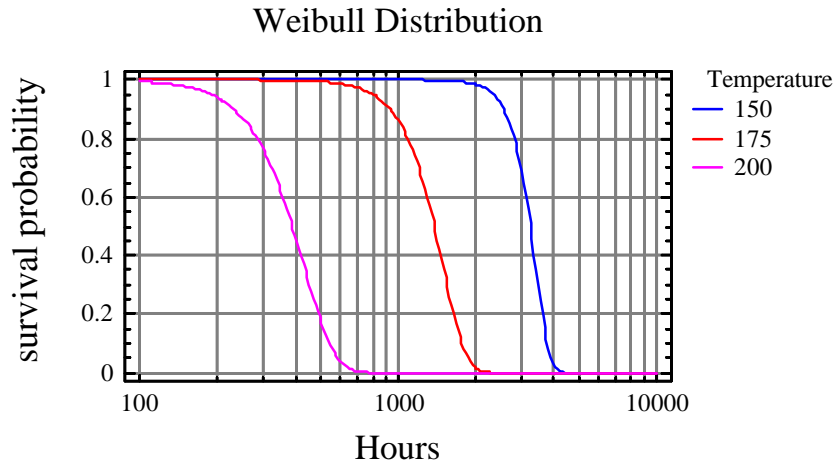
Product Reliability

A major issue with many manufactured items is product reliability. An important element of many quality-improvement efforts is estimating the mean time between failures as well as the entire failure-time distribution. STATGRAPHICS *Plus* contains a variety of tools for failure-time data, including the ability to fit any of 24 probability distributions in the presence of censoring.

Censoring frequently occurs when product lifetimes are tested because tests often end before each item fails. In situations such as this, the Weibull distribution is often used to estimate the proper handling of the censoring data. The distribution (in the figure below) has been fit to a set of failure and removal times to estimate the time at which 90 percent of the items will have failed. Failure times are shown as points, while the censored removal times are shown in the histogram. The plot also displays the 90th percentile with approximate 95 percent confidence limits.



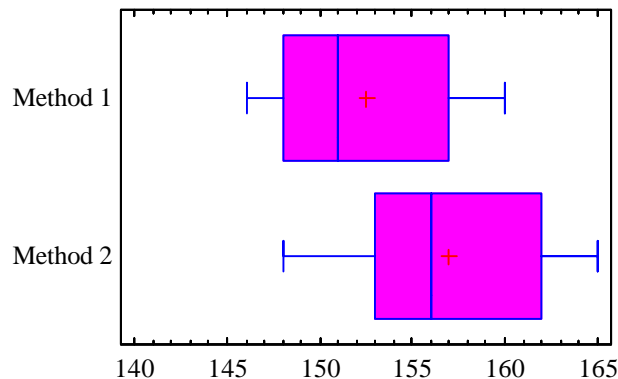
If a product is designed to last for long periods of time, estimating the failure-time distribution may not be possible under normal operating conditions. Often variables like **temperature** must be used to accelerate the failure rate. The percentiles that result can then be extrapolated to normal operating conditions to estimate failure-time distributions that cannot be observed directly. The Arrhenius Plot analysis is used for the extrapolation.



Comparing Two Populations

Many situations exist when data are collected from two different populations and it becomes necessary to determine if a significant difference exists between the two sets of data. For example, the samples may come from two production lines, two different shifts, or from using two different production methods. Displays like Box-and-Whisker plots and statistical techniques like *t*-tests can be used to determine the significance of an apparent difference.

Box-and-Whisker Plot




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Comparison of Means
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t test to compare means

Null hypothesis: mean1 = mean2
Alt. hypothesis: mean1 NE mean2
    assuming equal variances: t = -3.10895    P-value = 0.00315397

The StatAdvisor
-----
A t-test may also be used to test a specific hypothesis about the
difference between the means of the populations from which the two
samples come. In this case, the test has been constructed to
determine whether the difference between the two means equals 0.0
versus the alternative hypothesis that the difference does not equal
0.0. Since the computed P-value is less than 0.05, we can reject the
null hypothesis in favor of the alternative.

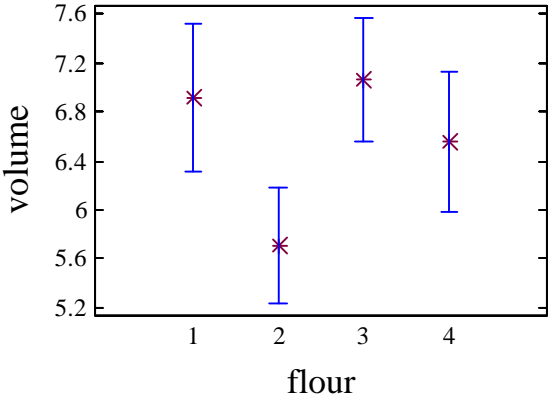
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Unique to STATGRAPHICS *Plus* is the *StatAdvisor*, which as in the table above, adds a simple explanation of the results of each statistical analysis to aid the practitioner in proper interpretation of the results.

Analysis of Variance

When it is necessary to compare several groups of data, an analysis of variance (ANOVA) is used, which determines if significant differences exist among the groups of data, and if so, which groups are significantly different from the others. The figure below shows the results of a Tukey HSD Intervals test, which assesses statistically significant differences between groups by determining if the intervals overlap.

Means and 95.0 Percent Tukey HSD Intervals



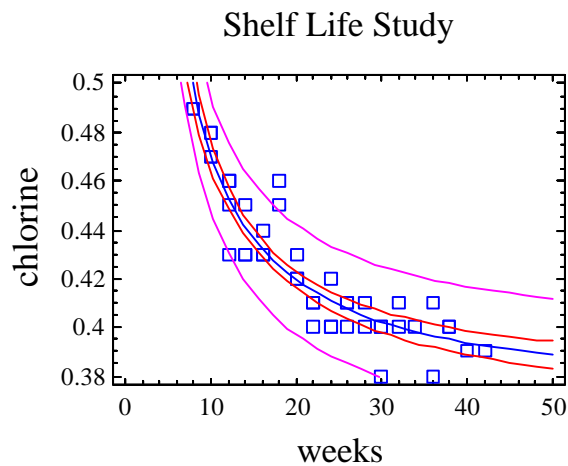
Attribute Data

While many statistical techniques can deal with variable or measurement data, much of the data collected for quality-improvement efforts involve product attributes. There are many analyses in STATGRAPHICS *Plus* that pertain to rates and proportions, such as an analysis of means plot for proportions defective.

Regression Analysis and Curve Fitting

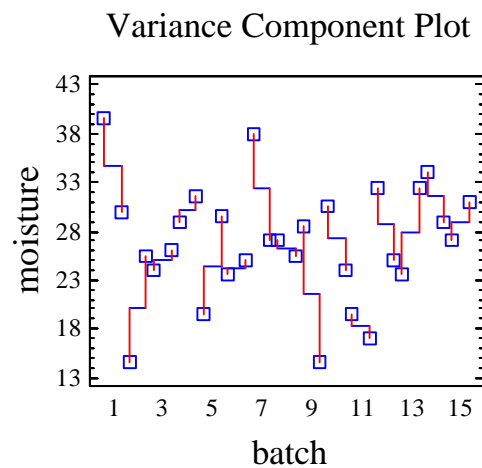
Once a list of the important variables that affect a process are identified, it is usually necessary to model the relationship between the influential variables and the quality characteristics. Statistical techniques helpful in constructing these models include calibration models and regression analyses such as those in *STATGRAPHICS Plus*: multiple regression, stepwise regression, logistic regression, and polynomial regression.

The figure below is a regression analysis that estimates the mathematical relationship between the response variable, Y, and one or more predictor variables, X.



Analyzing Variance Components

An important aspect in understanding where variations in product quality are occurring is determining the variability at different levels of a process. The results are shown in a Variance Component Plot.



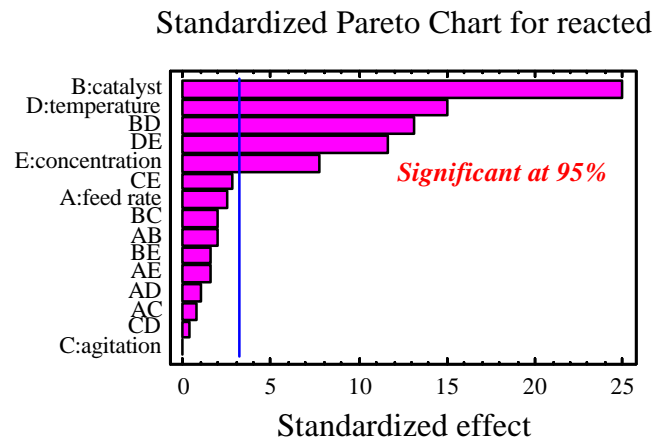
Experimental Design

Analysts and engineers must find operating regions where the characteristics they desire can be maintained throughout the rigors of day-to-day production. This makes it necessary to design quality into the product, not merely take corrective action when things go wrong. Statistically designed experiments can provide a consistent and economical means for understanding a process so it can be improved and maintained for product quality.

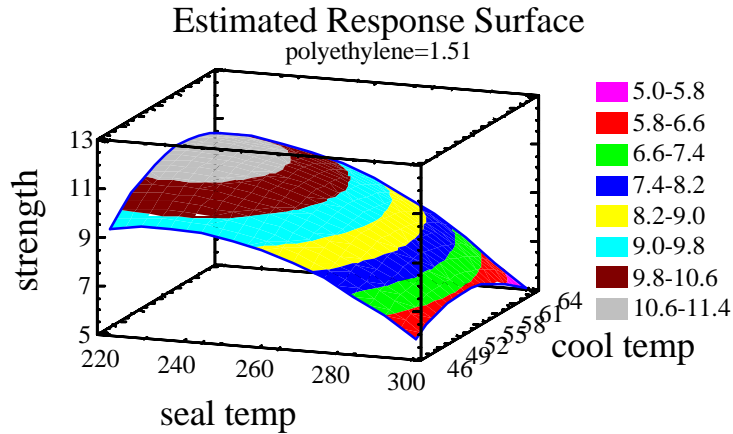
The experimental design analyses in STATGRAPHICS *Plus* are used to create many different types of experimental designs, including determining which variables have the most impact on quality characteristics, finding optimal settings for the most important factors, determining the best proportions of components to use in a mixture, discovering the most robust operating conditions when a process is insensitive to variations in uncontrollable noise factors, comparing levels for one or more categorical factors, and estimating the relative importance of different variance components on overall product variability.

STATGRAPHICS *Plus* provides both classic and modern designs, including full and fractional factorials, central composites, Plackett-Burman, Box-Behnken, Latin squares, Balanced Incomplete Block (BIB), as well as D-optimal and Taguchi-type designs (Inner/Outer Arrays).

STATGRAPHICS *Plus* analyzes the experimental results and plots them using the most appropriate statistical methods; for example a Standardized Pareto Chart.



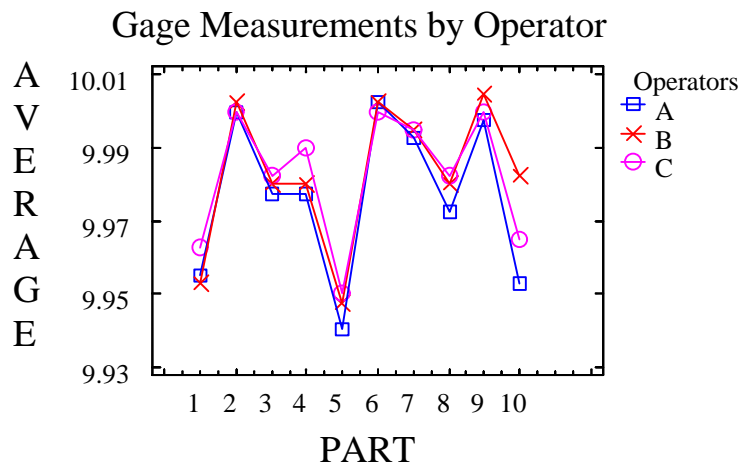
In addition to indicating which variables have a statistically significant impact on the responses, various graphs are available to display the relationships between the experimental factors and the response variables. For example, a Response Surface Plot illustrates a fitted statistical model.



It is also possible to numerically locate optimal conditions for one or more responses and then display them on a Contour Plot, which leads to a better understanding of the underlying relationships in a process and improved performance.

Gage R&R Studies

Before attempting to improve product quality by applying a statistical method, it is vitally important to ensure that the quality characteristics can be measured with the preciseness necessary to estimate the impact of changes to the process. A Gage R&R study quantifies measurement error by estimating the repeatability and reproducibility of a measurement process. In a typical study, several operators each measure a selected set of items more than once.



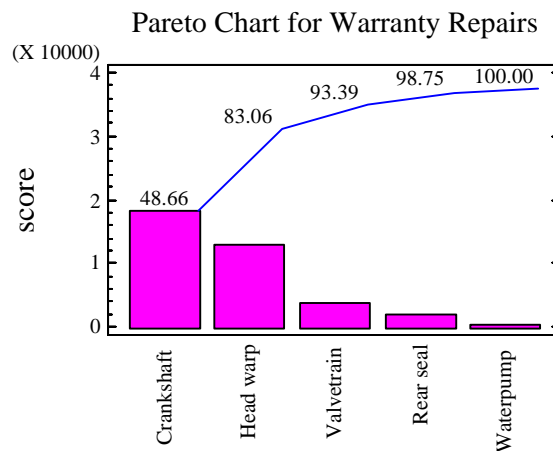
Vital information about operator-to-operator differences as well as the overall measurement process is gained through this type of study. A Gage R&R analysis quantifies the extent of measurement error and compares it to product tolerances.

The precision-to-tolerance ratio (P/T) in the Gage Report, shows the comparison of the measurement error with the width of the specification. A value below 10 percent is very good and shows that the measurement process is capable of distinguishing between good and bad items.

Pareto Analysis

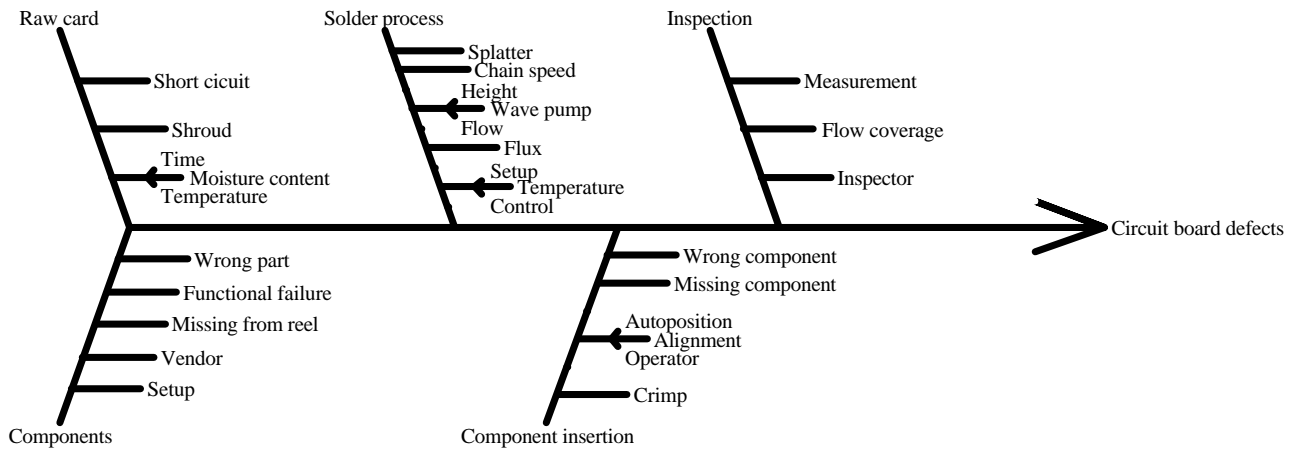
The principal objective of quality-cost analysis is identifying opportunities for improvement in a process or "honing in" on the select few areas that will yield the greatest payoff. A classic method for determining the "vital few" is using the Pareto Chart Analysis.

In this analysis, the various types of defects are sorted from the most frequent to least frequent. The data are plotted, and a line is drawn above the bars to show the cumulative percentage. Frequencies may also be weighted according to cost or seriousness and the scores are tabulated.



Cause-and-Effect Diagrams

Another technique useful for improving process quality requires that there is a thorough understanding of the various mechanisms that can lead to problems. Fishbone diagrams are especially helpful for displaying the results of brainstorming sessions.

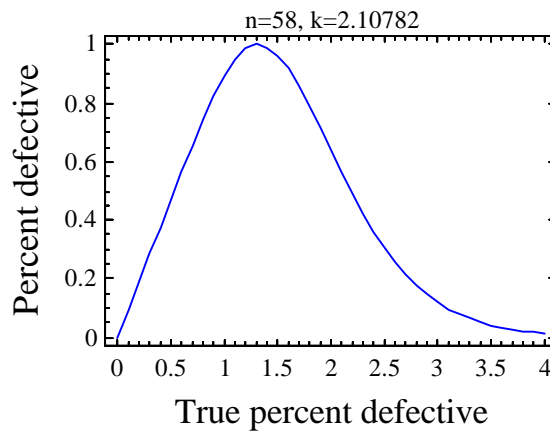


Acceptance Sampling

When large lots are inspected for purposes of acceptance or rejection, sampling plans are useful for specifying the number of items that must be examined. Acceptance sampling plans in *STATGRAPHICS Plus* are based on both attribute and variable data.

The average outgoing quality limit (AOQL) in the sampling plan shows the maximum percent of defective items permitted by that plan.

Average Outgoing Quality (AOQ) Curve



These types of statistical sampling plans help ensure that the product will not be accepted unless it meets well-defined quality requirements.

Conclusions

To compete in the world market, companies have to move toward a Six Sigma level of performance. The preceding has been a very brief overview of a few of the hundreds of statistical tools available in the STATGRAPHICS *Plus* software that can help achieve that goal.

In practice, integrating STATGRAPHICS *Plus* into a Six Sigma program should translate into cost reduction and profit improvement because:

- It helps define specification limits and set realistic tolerances for machines and process variables using capability indices.
- It helps companies set up a plan of action for processes that highlight out-of-control conditions and helps establish preventive maintenance controls to ensure that products meet specification requirements.
- It helps provide prevention plans during production with techniques for establishing and controlling critical machine parameters and product characteristics.
- It provides techniques that can reduce setup and process variability, and help to standardize the use of SPC methodology.
- It contains methodologies for optimizing processes; for example, Design of Experiments techniques to identify and reduce causes of variation and to improve product/process manufacturability, design, quality, and functionality.

STATGRAPHICS *Plus* can be a capable component of any company's Six Sigma program. The combination of text and graphical information accessed through an easy-to-use interface is a way to address the largest impediments to success for any Six Sigma program; the barriers to empowering all employees in the enterprise and keeping them engaged in the process. STATGRAPHICS *Plus* provides Six Sigma statistical analysis and reporting for everyone.