LabVIEW™ Statistical Process Control Tools

Revision C

This user guide contains requirements for using the Statistical Process Control (SPC) Tools, installation instructions, and information about upgrading from a previous version of the tools. It also includes descriptions of the SPC VIs, controls, and examples.

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Related Documentation

The following documents contain information you might find helpful as you read this user guide:

- *LabVIEW User Manual*
- *LabVIEW QuickStart Guide*
- American Society for Quality Control. *American National Standard. Definitions, Symbols, Formulas, and Tables for Control Charts*, 1987. Publication number: ANSI/ASQC A1-1987.
- Breyfogle, Forest W., *Statistical Methods for Testing, Development, and Manufacturing*, John Wiley and Sons, 1992.
- Montgomery, Douglas C., *Introduction to Statistical Quality Control*, J. Wiley and Sons, 2nd edition, 1991.
- Wheeler, Donald J. and Chambers, David S., *Understanding Statistical Process Control*, SPC Press, 2nd edition, 1992.

Requirements for Using the SPC Tools

Some of what you need to build an SPC application is already part of the LabVIEW programming environment. The SPC Tools package adds the missing pieces you need to complete your application. The SPC Tools consist of a set of VI libraries that implement key SPC functions such as control charts, process statistics, and Pareto analysis. The SPC Tools also contain several custom controls for SPC graphical presentations.

To use SPC effectively, you must be trained in SPC methods. SPC training is necessary because success in an SPC program depends on educated judgment and experience. Rote application of pre-existing templates is no substitute for this judgment. The SPC Tools package is a way to use LabVIEW to create SPC applications. If you are using this package to analyze and improve your process, you must receive training in SPC methods or have access to someone who has SPC expertise.

Two sources about SPC methods are the Wheeler and Chambers work and the Montgomery work cited in the *Related Documentation* section. The first reference describes how to apply SPC methods, and the second reference provides a theoretical and mathematical basis for SPC.

You must have LabVIEW programming experience to use this package. You can explore the simple examples included in the `SPC_EXMP` library after reading the *LabVIEW Quick StartGuide* and Chapter 1, *Introduction*, in the *LabVIEW User Manual*, which cover basic LabVIEW principles. To modify the more advanced SPC application examples successfully, you must be an advanced LabVIEW user.

Installation

The following sections contain instructions for installing the SPC Tools. The SPC Tools come in compressed form on CD-ROM, and installation requires approximately 4 MB.

If you need to install on a system without a CD drive, either mount it as a volume over a network or create a set of floppies from the directory on the CD.

The SPC Tools work with LabVIEW Version 5.1, or later, and BridgeVIEW Version 2.1, or later. If you have a previous version of LabVIEW or BridgeVIEW, the CD also includes a tools version that is compatible with LabVIEW 5.0 and BridgeVIEW 1.*x*. You can find the installers for this version in the `\OLD` directory on the CD.

Windows

Complete the following steps to install the SPC Tools for Windows.

1. **(Windows NT)** Log on to Windows NT as an administrator or as a user with administrator privileges.

2. Run `x:\SETUP.EXE`, where `x` is the drive letter for your CD-ROM drive.

3. After you choose an installation, follow the instructions that appear on your screen. When the installer prompts you to choose a destination folder, select your `LabVIEW` or `BridgeVIEW` directory.

After you install the SPC Tools, the **Functions** and **Controls** palettes will contain SPC entries the next time you launch LabVIEW or BridgeVIEW.

Macintosh

Complete the following steps to install the SPC Tools for Macintosh.

1. Insert the SPC Tools CD into your CD-ROM drive and double-click the LabVIEW SPC Tools Installer icon.
2. After you click the **Install** button, you are prompted to select a destination directory. Select your `LabVIEW` folder.
3. Follow the instructions on the screen.

After you install the SPC Tools, the **Functions** and **Controls** palettes will contain SPC entries the next time you launch LabVIEW.

UNIX

Complete the following steps to install the SPC Tools for UNIX.

Solaris 2

1. To enable superuser privileges, type `su root` and enter the root password.
2. Insert the SPC Tools CD. On Solaris 2.*x*, the CD automatically mounts as soon as the CD is inserted into the drive. If this feature is disabled on your workstation, you must mount the CD by typing the following command:

   ```
   mount -o ro -F hsfs /dev/dsk/c0t6d0s2 /cdrom
   ```
3. If your CD mounted automatically, type the following command:

   ```
   pkgadd -d /cdrom/cdrom0/solaris2
   ```
4. If you used the mount command in step 2, type the following command:

   ```
   pkgadd -d /cdrom/solaris2
   ```
5. Follow the instructions on your screen.

HP-UX 10.*x*

1. To enable superuser privileges, type `su root` and enter the root password.
2. Mount the SPC Tools CD on the `/cdrom` directory with the SAM system administration utility.
3. To change to the installation directory, type the following command:

   `cd /cdrom/HP-UX`
4. To run the installation script, type the following command:

   `./INSTALL`
5. Follow the instructions on your screen.

PowerMAX

1. Insert the 4 mm DAT tape into the tape drive.
2. To change to the LabVIEW directory, type the following command:

   `cd /opt/lv51`

   where `lv51` is your LabVIEW directory.
3. Extract the files from the tape by typing the following command:

   `tar xv`
4. To run the installation script, type the following command:

   `./INSTALL`

Follow the instructions on your screen.

Files and Directories

After you install the SPC Tools, the following files and directories are located on your hard drive inside the directory that contains your LabVIEW or BridgeVIEW application:

- `vi.lib\addons\SPC`—Directory that contains the VIs accessible through the **SPC** function and control palettes.
- `examples\SPC`—Directory that contains example SPC VIs.

Compatibility Issues

The SPC Tools are compiled for LabVIEW 5.1 and BridgeVIEW 2.1, but they also work with later versions of LabVIEW and BridgeVIEW. If you install these Tools into a system with a later version of LabVIEW or BridgeVIEW, you must mass compile the `VI.lib\addons\SPC` and `examples\SPC` directories before you use the SPC VIs.

Upgrading from the Previous Version

This section provides an overview of how to upgrade from previous versions of the SPC Tools. This section also describes the improvements and bug fixes for version 1.0.

Note The SPC installer may overwrite files located in the `VI.lib\addons\SPC` and `examples\SPC` directories. Before you install the new version of the SPC Tools, please backup any user-created files located in these directories.

Features Introduced in Revision C

Revision C introduces the following new features:

- Controls—When you place a custom SPC control on your front panel, the subVI required to format the data for display on the graph is automatically placed on the block diagram.

  In previous versions of the SPC Tools, custom XY graphs and graphing VIs were provided to aid in the display of process statistics and control charts; however, the graphs did not automatically add the required subVI to the block diagram. If you prefer using the older style custom controls included in the previous versions of the SPC Tools, you can access them by selecting **SPC»Control Charts»Control Charts Controls** and **SPC»Process Graphs»Process Graphs Controls**.
- VIs—The VIs used to format your SPC data for display on the custom XY graphs now are located on the **SPC»Control Charts»Control Chart Drawing VIs** and **SPC»Process Statistics»Process Statistics Graphing VIs** palettes.

Refer to the *SPC Tools* online help for detailed descriptions of the SPC controls and VIs.

Bug Fixes in Revision C

This version of the SPC Tools contains the following bug fixes:

- The examples now correctly handle the boundary condition, so all points are not found to be out of control.
- The examples containing broken wires to attribute nodes are corrected.
- The installer now works on NEC Windows machines.

Important Note for LabVIEW Full Development and Professional Development Users

The General Histogram and Normal Distribution VIs included in the SPC Tools are functionally and connector pane compatible with the Advanced Analysis Library General Histogram and Normal Distribution VIs. If you have the Advanced Analysis Library, you might consider using those versions of the VIs because they execute approximately six times faster.

SPC Tools Organization

The SPC Tools are organized in three sections—VI Libraries, Custom Controls, and Examples.

VI Libraries

To access the SPC VIs, select **Functions»SPC**. The **SPC** palette contains the following three subpalettes:

- **Control Chart** palette—Includes VIs for calculating control chart limits for attributes and variables charts, drawing control chart graphs, and applying run rules to control charts.
- **Process Statistics** palette—Includes VIs for estimating process distribution and capability, calculating and plotting histograms, and functions for plotting and fitting normal probability distribution functions to histograms.
- **Pareto Analysis** palette—Includes VIs for counting and sorting assigned causes and for creating Pareto charts.

The SPC VIs are described in more detail in the *SPC VIs* section later in this document.

Custom Controls

A set of custom controls for SPC graphs and legends are installed as part of the **Controls** palette. When you place an SPC custom control on your front panel, a subVI that is already wired to the control also is placed on the block diagram. The SPC controls are grouped into three categories, similar to the VI libraries—Control Charts, Process Graphs, and Pareto Charts.

You can access the following control chart controls by selecting **Controls»SPC»Control Charts**:

- Control Chart—A pre-formatted XY graph with points and limit lines drawn. This control also includes a legend cluster that displays values for the control chart lines. This chart uses the Draw Control Chart VI as a subVI.

- Control Chart with Zones—A pre-formatted XY control chart graph with points and horizontal zone lines drawn. This control also includes a legend cluster displaying values for the control chart zones A, B, and C. This chart uses the Draw Chart with Zones VI as a subVI.
- Chart with Variable Limits—A pre-formatted XY control chart graph with points and variable limit lines drawn. This control also includes a legend cluster that displays values for the control chart lines. This chart uses the Draw Chart with Variable Limits VI as a subVI.
- Tier Chart—A pre-formatted XY graph with the observations in each sample plotted vertically with limit lines drawn. This chart uses the Draw Tier Chart VI as a subVI.
- Run Chart—A pre-formatted XY graph with the individual observations in each sample plotted in order of occurrence with limit lines drawn. This chart uses the Draw Run Chart VI as a subVI.

You can access the following process graph controls by selecting **Controls»SPC»Process Graphs**:

- Histogram Bar Graph—A pre-formatted XY bar graph. This graph uses the Plot Vertical Bar Graph VI as a subVI.
- Histogram Bar Graph with Limits—A pre-formatted XY bar graph with limits optionally drawn at the natural process limits and specification limits. This graph uses the Plot Vertical Bar Graph with Limits VI as a subVI.
- Normal PDF Graph—A pre-formatted XY graph of a normal PDF. This graph uses the Plot Normal PDF Graph VI as a subVI.
- Normal PDF Graph with Limits—A pre-formatted XY normal probability distribution graph drawn with specification limits and natural process limits. This graph uses the Plot Normal PDF Graph with Limits VI as a subVI.
- Histogram and Normal PDF Graph—A pre-formatted XY graph with a histogram and superimposed normal PDF plot with limits. This graph uses the Plot Histogram and Normal PDF VI as a subVI.

You can access the following Pareto chart controls by selecting **Controls»SPC»Pareto Charts**:

- Pareto Chart (frequency)—A pre-formatted XY bar graph of frequency of occurrence of each cause with superimposed cumulative plot of frequency. This control also includes a pre-formatted legend table. This chart uses the Plot Pareto Chart VI as a subVI.
- Pareto Chart (percent)—A pre-formatted XY bar graph of percent of total of occurrence of each cause with superimposed cumulative plot of percent of total. This control also includes a pre-formatted legend table. This chart uses the Plot Pareto Chart VI as a subVI.

LabVIEW SPC Tools Examples

The SPC Tools include two example libraries. The `SPC_EXMP.llb` library contains basic to intermediate SPC examples. These examples are useful for getting started and learning how to group the SPC VIs to perform typical SPC calculations and presentations.

The `SPC_DEMO.llb` (SPC demonstration library) contains an example application, `Real-time SPC Demo`, that analyzes process data acquired point by point. It also contains an advanced VI you can modify once you are proficient at using the SPC Tools.

The example libraries are located in the SPC directory in your LabVIEW folder or directory.

SPC VIs

This section describes the SQL VIs, which you access by selecting **Functions»SPC**. From the **SPC** palette, you can access the following subpalettes:

- **Control Charts** palette
- **Process Statistics** palette
- **Pareto Analysis** palette

Control Chart VIs

This section describes the control chart VIs, which include the variables charts, attributes charts, chart drawing, and rule checking VIs. The control chart VIs compute control limits for control charts, create control chart graphs, and apply rules to control chart data that detect out-of-control conditions.

Calculating Control Chart Limits and Points

The variables and attributes chart VIs compute the points to plot on the control charts, and the center line and control limits for the control chart. The process data input to the chart VIs is a one- or two-dimensional array of samples. The control chart VIs pass output arrays and chart limits clusters to one of the chart drawing VIs to create the desired control chart graph.

The **chart limits** cluster contains the upper control limit (UCL), center line (CL), lower control limit (LCL), and the standard error from which the upper and lower control limits are calculated. The default limits are center line ±3.0 standard errors.

To compute the control limits from the input sample data, select a subset of the array input to the Control Chart VI by wiring an index specifier. The index specifier designates the start and end index of the samples that the control chart limit calculations use. You also can exclude specific samples from the control limit calculation by wiring an array of the sample indices to the **indices to ignore** input of the VI. Doing this is useful when samples are detected to be out of control by one of the rule checking VIs. The **# samples in calc** output returns the actual number of samples the VI used to calculate the control limits. If you do not wire either input, the VI calculates the control limits from the entire input array.

Normally the control limits are calculated from the input sample data. However, the control chart VIs calculate control limits based on standard values if you wire the **chart limit src** input cluster.

The standard error multiplier input specifies the multiplier for the VI to use when calculating the upper and lower control limits, normally 3. You do not need to wire this input unless you are using upper and lower control limits that are not ±3.0 standard errors.

Variables Chart VIs

You can use variables charts to detect out-of-control conditions on measured process values. The VIs for creating variables charts generate outputs for two control charts—sample mean and sample variation. The chart for sample mean tracks variation in the mean of each sample against control limits. The chart for sample variation tracks the variation in the distribution of each sample against control limits.

The following variable chart VIs are available. You can access these VIs by selecting **Functions»SPC»Control Charts**. For detailed information about these VIs, pop up on the VI and select **Online Help** from the pop-up menu.

- x-Bar & s Chart VI
- x-Bar & R Chart VI
- x & mR Chart VI
- mX-bar & mR Chart VI
- Single Point X-Bar & R/S VI
- Single Point x/mX-bar & mR VI

The x-bar & s Chart VI and the x-bar & R Chart VI take a two-dimensional input array of samples, where each column contains an individual observation within a sample, and each row is a sample. The sample size is the number of columns in the 2D array. The x-bar & R Chart VI is limited to sample sizes of 25 or less (25 columns). The x-bar & s Chart VI has no limit on the sample size.

The x & mR Chart VI and mX-bar & mR Chart VI take a one-dimensional input array of individual observations. The VIs calculate the moving average range from *n* consecutive observations, where *n* is sample size input. By default, *n* is set to 2.

The Single Point X-bar & R/S VI calculates points for sample mean and variation control charts one sample at a time and uses both the range and sample standard deviation calculations. This VI is useful for calculating individual points when generating control charts in real time. You still must use the x-bar & s Chart VI or the x-bar & R Chart VI to calculate the control limits.

The Single Point x/mX-bar & mR VI calculates the individual points for an X and moving range or moving average and moving range control chart. This VI is useful for calculating individual points for a control chart when generating control charts in real time. You still must use the x & mR Chart VI or the mX-bar & mR Chart VI for calculating the control limits.

Attributes Chart VIs

You can use attributes charts to detect out-of-control conditions on process data that is counted, such as the number of parts defective in a sample of *n* units inspected.

The SPC Tools include the following attribute chart VIs. You can access these VIs by selecting **Functions»SPC»Control Charts**. For detailed information about these VIs, pop up on the VI and select **Online Help** from the pop-up menu.

- p Chart VI
- np Chart VI
- c Chart VI
- u Chart VI

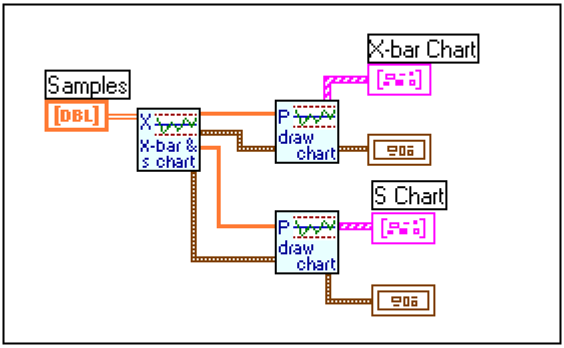
The attributes chart VIs take one or more 1D arrays as the input data. The p chart and u chart can handle both a fixed sample size or variable sample sizes. If the sample sizes are variable, the VI calculates the variable control limits.

The attributes chart VIs generate outputs for a single control chart. Inputs are one or more 1D arrays that contain values counted from the process. The output includes an array of points for the control chart and the chart limits. In the case of the p chart and the u chart, the sample size inspected can vary for each value of **# units non-conforming**, or the sample size can be constant. So, you can choose one of the following two inputs: a scalar input for a constant number inspected, *n*, or an array input for a variable number inspected, *n*. Use only one of these two inputs.

The output arrays UCL and LCL are the variable control limits (p and u charts only). The **chart limits** cluster contains the average UCL, CL, average LCL, and the standard error from which the VI calculates the upper and lower control limits.

VIs for Drawing Charts

The **Control Charts»Control Chart Drawing VIs** palette contains several VIs for graphing control charts and raw process data. You also can use the built-in LabVIEW waveform chart and XY graphs to present SPC data. The VIs in this library use the XY graph to draw limits against control chart points, a format that is typical of SPC graph presentations. The following illustration shows a typical diagram using the control charts and draw control charts VIs.



The **SPC** controls palette contains custom, preformatted controls. The custom controls consist of a control chart VI wired to the appropriate chart. For example, the Control Chart control includes an XY graph that is already wired to the Draw Control Chart VI.

VIs for Plotting Control Chart Points and Limits

The control chart VIs calculate control chart limits and points. The following VIs generate a graph of center lines, the upper and lower limit lines, and the computed points from the control chart. You can access these VIs by selecting **Functions»SPC»Control Charts»Control Chart Drawing VIs**. For detailed information about these VIs, pop up on the VI and select **Online Help** from the pop-up menu.

- Draw Control Chart VI—Draws a basic control chart graph for use with constant control limits.

- Draw Chart with Zones VI—Draws zones or warning limits from constant control limits, which is useful for testing run rules.
- Draw Control with Variable Limits VI—Creates a variable limits control chart for use with variable control limits (p and u charts).

VIs for Creating Graphs of Raw Process Data

The Draw Run Chart and Draw Tier Chart VIs create graphs that are independent of the type of control chart you use and are convenient for viewing the individual observations that make up your samples. This class of graphs optionally plots your data against specification limits or natural process limits.

Specification limits are user-defined tolerances for the process output. Natural process limits are computed from the samples and represent the process mean and 3 sigma. The natural process limits are not control limits but are a statistic of the variability in your raw data.

The Draw Run Chart and Draw Tier Chart VIs are described below. You can access these VIs by selecting **Functions»SPC»Control Charts»Control Chart Drawing VIs**. For detailed information about these VIs, pop up on the VI and select **Online Help** from the pop-up menu.

- Draw Run Chart VI—Plots a run chart of the individuals within each sample in order of occurrence. This VI optionally displays specification limits and/or natural process limits (process mean and 3 sigma) against the data.
- Draw Tier Chart VI (variables charts only)—Plots all observations (individuals) within each sample. This VI optionally displays specification limits and/or natural process limits (process mean and 3 sigma) against the data.

These VIs have a display mode specifier that you can use to turn on and off drawing of the specification limits or the natural process limits. The display specifier also designates the sigma multiplier for the VI to use for the natural process limits (default 3). You can leave the display mode input unwired, in which case the graphing VI uses the defaults. The defaults are not the same for all the VIs.

The x-axis on all the graphs on the **Control Charts** palette is labeled by sample number. The default starting sample number is zero. You can wire a different number to suit your needs. Notice that array index counting in LabVIEW is zero-based. Therefore, numbering samples starting from zero is the least confusing method to use. The control chart VIs use simple (X,Y) pairs to define horizontal limit lines drawn on the XY graph.

You also can use waveform charts, or strip charts, to plot your control charts, in which case the VI passes information to the chart one sample at a time. The SPC Tools do not provide special VIs for strip chart presentation; however, you can use the standard LabVIEW waveform chart. To draw control chart, natural process, or specification limits against your control chart points, cluster the limit values with your point, and wire the cluster to your waveform chart. To see an SPC application using a strip chart, run the "Real Time" SPC Demo VI located in `Examples\SPC\Spc_demo.llb`.

Rule Checker VIs for Testing Out of Limits, Run Rules, and Process Shift

The SPC Tools contain the following rule checker VIs to test if points exceed the control limits or if any of the run rules are violated, and to detect process shift. You can access these VIs by selecting **Functions»SPC»Control Charts**. For detailed information about these VIs, pop up on the VI and select **Online Help** from the pop-up menu.

- Check Control Limits VI—Identifies samples that exceed the upper and lower control limits.
- Rule Checker (AT&T/WE) VI—Identifies samples that violate one or more of the selected AT&T/Western Electric run rules.
- Rule Checker (Nelson) VI—Identifies samples that violate one or more of the selected Nelson run rules.
- Process Shift Detector VI—Detects process shift with respect to center line.
- Sequence Checker VI—Identifies samples violating a generic *n* out of *m* sequence.

After a VI has identified out-of-control points, you can wire the rule checker VI output to the indices input of the control chart VIs and exclude these samples from the control limit calculation.

Process Statistics VIs

This section describes the process statistics VIs, which are useful for process capability analysis and for viewing and measuring process distribution.

The process statistics VIs perform the following operations:

- Compute process mean and sigma
- Compute process capability ratios and reject rates

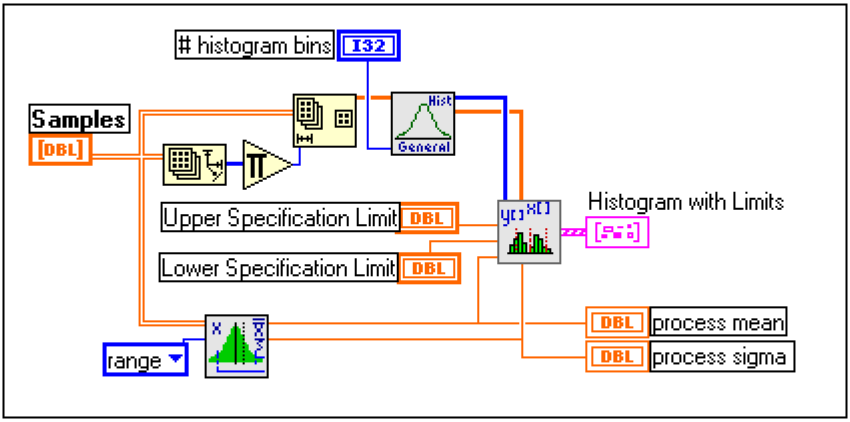
- Create and graph histograms
- Plot normal probability distribution functions against histograms and process specification limits

The following Process Statistics VIs are available. You can access these VIs by selecting **Functions»SPC»Process Statistics**. For detailed information about these VIs, pop up on the VI and select **Online Help** from the pop-up menu.

- Process Mean and Sigma VI—Computes process mean and sigma and upper and lower natural process limits from process samples. You can estimate the process sigma in several ways. If the sample size is greater than 1, you can use either sample standard deviation s or range R to estimate the process sigma. You select s or R by the type input. If the sample size is 1, the VI automatically uses the moving range to estimate the process sigma.
- Compute Process Capability VI—Given the specification limits and the **process mean** and **process sigma**, computes the process capability ratios **Cp**, **Cpk**, and **Cpkm** as well as the estimated process fraction non-conforming in parts per million (ppm). Notice that the fraction non-conforming is valid only if the process is normally distributed. This VI computes one-sided upper and one-sided lower in addition to two-sided process capability ratios and fraction non-conforming.
- Sample Statistics VI—Computes statistics on the input array **sample X**.
- General Histogram VI—Finds the discrete histogram of the input sequence **X** based on the given bin specifications.
- Fit Nrml PDF to Histogram VI—Given the bin centers from a histogram (axis values output from the General Histogram VI), the estimated sigma of the observations for the histogram, and the total number of observations in the histogram, calculates the height for a normal probability distribution function (PDF) that fits the histogram.

VIs for Graphing Process Statistics

The **Process Statistics** palette contains several VIs for graphing process graphs and raw process data. You also can use the built-in LabVIEW waveform chart and XY graphs to present SPC data. The VIs in this library use the XY graph to draw limits against process graph points, a format that is typical of SPC graph presentations. The following illustration shows a typical diagram using the process statistics VIs.



The **SPC** controls palette contains custom, preformatted controls. The custom controls consist of a process statistics graphical VI wired to the appropriate graph. For example, the Histogram Bar Graph control includes an XY graph that is already wired to the Plot Vertical Bar Graph VI.

The following Process Statistics Graphing VIs are available. You can access these VIs by selecting **Functions»SPC»Process Statistics»Process Statistics Graphing VIs**. For detailed information about these VIs, pop up on the VI and select **Online Help** from the pop-up menu.

- Plot Normal PDF Graph with Limits VI—Given the specification limits and the **process mean** and **process sigma**, creates a graph of a normal PDF of the process against the specification limits and process mean and sigma.
- Plot Normal PDF Graph VI—Given the process mean and sigma, creates a graph of a normal PDF for the process. Also returns an array of XY values for the normal distribution. This graph is useful for viewing the estimated distribution of a sample or group of samples and for plotting a normal PDF against a histogram.
- Plot Vertical Bar Graph with Limits VI—Creates a vertical bar graph centered at each of the bin centers x[ ] and plots the specification limits and natural process limits as vertical lines against the bar graph. This type of bar graph is useful for viewing the results of a histogram against relevant limits.
- Plot Vertical Bar Graph VI—Creates a centered vertical bar graph. Bars are centered at the x[ ] values with height y[ ]. This VI can be used to plot a histogram.
- Rotate Graph VI—Given a multi-plot XY graph, transposes the X and Y values so that the graph is rotated clockwise 90 degrees.
- Plot Histogram & Normal PDF VI—Creates a graph of a normal PDF of the process and a vertical bar graph centered at each of the bin

centers x[] against the specification limits and process mean and sigma, given the specification limits and the process mean and sigma.

Pareto Analysis VIs

This section describes the Pareto Analysis VIs, which include the Pareto Counter VI, the Plot Pareto Chart VI, and the Cause Code Lookup VI.

The following Pareto Analysis VIs are available. You can access these VIs by selecting **Functions»SPC»Pareto Analysis**. For detailed information about these VIs, pop up on the VI and select **Online Help** from the pop-up menu.

- Pareto Counter VI—Given an unsorted list of causes and the number of occurrences for each cause, sorts the list from the cause with the largest number of occurrences to the smallest and computes Pareto statistics for each cause.
- Plot Pareto Chart VI—Given a set of Pareto values (output of the Pareto Counter VI), creates two Pareto charts and the associated legend. One is a bar chart of the frequency of occurrence of each cause. The other is a bar chart of the percentage contribution of each cause. The legend is a list of cause codes with their rank in a table (2D array of strings) format.
- Cause Code Lookup VI—Given an unsorted list of numeric cause codes (an array of numbers), and a cause code lookup list containing the cause string for each cause code, returns a sorted list of causes with the count of the number of occurrences of each cause.

The Pareto Counter VI accepts two alternative inputs. You can pass in either an unsorted list of causes (an array of strings) or an array of clusters with each cluster containing a cause string and the corresponding total number of occurrences of that cause. If you use numeric cause codes instead of strings, you can use the Cause Code Lookup VI to count the number of occurrences of cause codes and generate a list of cause strings with the count for each cause to be passed to the Pareto Counter VI. If no cause string is given for a cause code, the code itself is put in string form.

Implementing SPC Applications in LabVIEW

This section describes the main components of an SPC application and guides you through some of the programming techniques you can use in your statistical processing. These programming techniques include representing process data, viewing raw process data, creating control charts to determine whether your process is in control, detecting out-of-control points, and using process capability and Pareto analysis.

This section also directs you to the relevant standard LabVIEW feature or the additional SPC Tools feature to use when implementing an application. Definitions of the SPC terms used in this overview appear in the *Glossary* at the end of this document. All examples mentioned in this section are located in the `SPC_EXMP.llb` library.

Representation of Process Data in LabVIEW

In SPC applications, key characteristics of a process are measured or counted, and then tracked. In this document, measurements of these processes are referred to as *individual observations* or *individuals*. These measurements are often grouped into *samples* or *subgroups*. The number of observations in a sample is referred to as the *sample size* or the *subgroup size*. Deciding which measurements to make, how many and how often to make them, and how they are grouped is beyond the scope of this document. Search for “rational subgrouping” in the sources cited in the *Related Documentation* section for more information about this topic.

In the SPC VIs for calculations on variable (measured) data, samples consisting of a number of individual observations are handled as 2D arrays. The arrays are set up where each row is a sample, and the columns contain the observations. To use these VIs, group your measured process data into appropriate 1D array samples (subgroups), and then group the samples together to form a 2D array. All samples in a 2D array must be the same size. The control chart VIs automatically calculate sample size by measuring the width of the 2D array. You can use the LabVIEW Reshape Array function to convert a 1D array to a 2D array.

If you have a sample (subgroup) size of one, you can keep your data in 1D arrays. In this case, you are limited to using the X & moving Range chart VI or the mX-bar & moving Range VI. Attribute data, such as number of defects per unit, are handled as 1D arrays.

There are two ways you can graphically present your measured data in LabVIEW—as you acquire each data point or sample or after you have acquired a collection of samples. LabVIEW has several standard methods for viewing process data. The three basic graph types—the waveform chart, the waveform graph, and the XY graph—are all useful.

You can implement a run chart, a plot of the individual measurements plotted in time order, by wiring a 1D array containing your observations to the standard waveform graph. If you want to monitor your incoming data one point at a time, use a waveform chart. If you are plotting all the points at once, use a waveform graph.

SPC charts typically plot process data against reference lines, which can be specification limits, control chart limits, or some other useful reference. In LabVIEW, you can use an XY graph to plot a set of points and reference lines by specifying the reference lines as XY pairs. The SPC Tools automatically generate these types of XY graphs for you.

The SPC Tools include a set of custom SPC controls, including XY graphs that are preformatted for various types of SPC charts and chart legends. These charts are preformatted to work with the SPC VIs that create SPC graphs.

If you are updating a waveform chart one point at a time, you can group each point into a cluster with the reference points and wire the cluster to your waveform chart.

Viewing Raw Process Data

You might need to view your raw process data before calculating control limits and plotting control charts. The SPC VIs provide three methods for viewing your raw process data—a basic run chart, a histogram, and a tier chart.

- Basic run chart—Consists of the individual measurements plotted in time order. A run chart is displayed on an XY graph and generated by the Draw Run Chart VI. The Run Chart control consists of the XY graph and the Draw Run Chart VI. The specification limits are shown against the individuals in the example. To see an example run chart, open and run the Basic Run Chart VI, located in `Examples/SPC/Spc_exmp.llb`.
- Histogram chart—The General Histogram VI computes a histogram, automatically estimating a reasonable number of bins based on Sturges' rule. You also can choose the number of bins and specify bin sizes. LabVIEW then plots the histogram using the Plot Vertical Bar Graph VI and an XY graph, which both are included in the Histogram Bar Graph control.

  You can superimpose the specification limits on the histogram, which the Plot Vertical Bar Graph with Limits VI does for you. Run the Basic Histogram Plot VI example to see a basic histogram plot of individual observations in a 2D samples array plotted against both the natural process limits calculated by the Process Mean and Sigma VI and the specification limits.
- Tier chart, also known as a tolerance diagram—Charts the observations in each sample in a straight, vertical line. With this vertical line plot, you can visualize the spread and location of the observations in each sample. The Draw Tier Chart VI generates the tier chart for you and is included in the Tier Chart control.

Another useful reference for viewing the raw process data is the natural process limits, calculated from the average mean and sigma of the group of samples. The natural process limits measure the distribution of the process data. The natural process limits are typically the process mean ± 3.0 * process sigma. The Process Mean and Sigma VI, in the process statistics library, estimates the process mean and sigma from the process samples.

Creating Control Charts and Determining Whether the Process is in Control

You can use control charts to determine if a process is in control. The LabVIEW SPC Tools VIs generate the following standard types of control charts:

- Variables charts
  - X-bar and standard deviation (X-bar & s Chart VI)
  - X-bar and range (X-bar & R Chart VI)
  - X and moving range (x & mR Chart VI)
  - moving average and moving range (mX-bar & mR Chart VI)
- Attributes charts
  - p (p Chart VI)
  - np (np Chart VI)
  - u (u Chart VI)
  - c (c Chart VI)

The control chart VIs calculate the control limits for a control chart. Normally, the control chart VIs use the process data to calculate the control limits. You must choose the set of samples from which to calculate the control limits. Variables charts typically use the first 20 to 30 samples of sample size four or five, for a total of about 100 individual observations of the process. The control chart VIs also can calculate control limits from standard values.

Once the VI calculates the limits, there are several ways to plot the control charts with corresponding VIs that generate the XY graphs for the different chart styles. The most common presentation is a control chart that draws the data against the three standard error control limits, as shown by the X-bar & S Control Chart example VI located in `Examples\SPC\Spc_exmp.llb`.

The Draw Chart with Zones VI divides the area among the three sigma control limits into six zones that are one sigma wide and draws the zones against the control chart points. This presentation is useful when you want to apply rules to the chart to detect out-of-control points. This use of a zones chart is illustrated in the Zone Rule Test (AT&T/WE) Example and the

Zone Rule Test (Nelson) Example VIs, located in `Examples\SPC\Spc_exmp.llb`.

Some attributes charts calculate variable control limits, which are plotted by the Draw Chart with Variable Limits VI. The p Chart with Variable Limits example VI, located in `Examples\SPC\Spc_exmp.llb`, uses the Draw Chart with Variable Limits VI.

Detecting Out-of-Control Points and Process Shift

After a variable or attribute chart VI calculates the control limits, you can determine if the process is in control. The most basic way to determine if a process is in control is to observe which points exceed the upper and lower control limits. The Check Limits VI identifies the index of each sample that exceeds the process limits.

The X-bar & Range Chart Check Limits example VI, located in `Examples\SPC\Spc_exmp.llb`, shows the Check Limits VI applied to an X-bar chart. Notice that out of the given 40 samples, 25 samples (index 0 to 24) are selected for calculating the control limits. The VI calculates the points of the remaining samples for the graph but does not include them in the control limit calculation.

Control points calculated from a process can stay within the control limits, but they still exhibit non-random behavior such as repeated patterns in the data. To detect patterns you can use the rule checker VIs to apply run rules to the control chart array. The run rules included in the SPC Tools are AT&T/Western Electric and Nelson rules. The rule checker VIs identify the indices of samples that violate the run rules. You can individually enable run rules. The Zone Rule Test (AT&T/WE) Example VI, located in `Examples\SPC\Spc_exmp.llb`, applies the AT&T/Western Electric rules to an X-bar chart.

After you identify samples that violate run rules, you can recalculate the control limits by calling the Control Chart VI again and passing in the list of sample indices to ignore.

Note Before ignoring a sample in a control limit calculation, you must know what caused the sample to be out of control (that is, you need to know the assignable cause).

You also can apply run rules to detect process shift, which indicates that control chart limits should be recalculated because the process has changed or shifted with respect to the center line. The Process Shift Detector VI uses four rules, described on the VI front panel, to detect process shift and identifies the first point of the process shift.

Process Capability Analysis

Using process capability analysis, you can quantify the ability of your process to create products within specification. Once your process is in control, you can calculate its capability, which is a predictor of the process performance, as long as the process remains in control. It is misleading to perform these computations unless your process is in control. If the process is not in control, process capability analysis is no longer predictive but can still characterize the past performance of your process.

Two common measures of process capability are the process capability index (PCI or Cp), which measures the process variability with respect to the specification limits, and the centered capability index, or Cpk, which measures how centered the process is with respect to the specification limits. The Compute Process Capability VI performs these calculations.

If your process is normally distributed, you can estimate the non-conforming process fraction in parts per million. The Compute Process Capability VI performs this computation but is invalid unless the process is normally distributed. One method for determining whether your process is normally distributed is to view a histogram of the observations against a normal curve fitted to the histogram.

You might find it useful to visualize the distribution of the process relative to the specification limits. Run the Proc Cap Example 1 VI to view a histogram of the process observations against the specification limits and natural process limits. A normal distribution curve is fitted to the histogram. The process capability measures, Cp, Cpk, and reject rate, also are calculated and displayed.

Pareto Analysis

In SPC applications, you might need to quantify and prioritize assignable causes that prevent a process from being in control or otherwise prevent a product from conforming to specifications. You can assign causes to a sample when you detect samples are out of control from a control chart. Other items can prevent a product from conforming to specifications that need to be analyzed, such as tabulated results from product inspection. You can total, order, and present causes using the Pareto VIs.

Glossary

A

Assignable Cause	A cause that can be detected and identified as contributing to process variation.
Attribute Data	Data from counting process results such as number of units non-conforming per inspected sample, or number of defects per inspected sample containing *n* units. As opposed to measured data, attribute data has a discrete number of possible values. p, np, u and c control charts are used to track attribute data.
Attributes Chart	A control chart that tracks whether a process is in control by tracking attribute data, or data counted from the process. p, np, u, c charts are attributes charts.

C

c Chart	Control chart that uses number of defects per sample to monitor the stability of the process. Each sample contains *n* units, and contains c defects per sample (zero or more defects per unit). The value of *n* must be constant from sample to sample.
center line	A line on a control chart representing average long-term value of the statistic plotted on the control chart.
control	Front panel object for entering data to a VI interactively or to a subVI programmatically.
control chart	A charting method for determining the stability of a process; that is, whether or not a process is in a state of statistical control. Shewart control charts monitor process stability by plotting sample statistics against a center line and control limits.
control limits	Upper and lower limits on a control chart represent the amount of variation about a center line that can be attributed to chance causes for a given process characteristic. Control chart points that fall outside the control limits signal that the process is not in control and that some action should be taken. Control limits may be calculated from process data or from standard values.
Cp process capability index	A measure in sigma units of the process capability that is a ratio of the spread between the specification limits over the *m* sigma spread of the process variation, where *m* normally is 6.

Cpk centered capability ratio	A measure in sigma units of the process capability with respect to how well the process is centered relative to the specification limits, also known as distance to nearest specification.
current VI	VI whose front panel window, block diagram window, or icon editor window is the active window.

D

defect	A measured characteristic of a specific unit of product or service that prevents the unit from meeting a specification requirement or is otherwise undesirable. In a unit, one or more defects are possible, and many different types of defects are possible. A defect is also known as a non-conformity if the characteristic prevents the unit from meeting a specification requirement.

F

fraction non-conforming	The number of units in a sample not conforming to specification divided by the total number of units in the sample.

H

Help window	Special window that displays the names and locations of the terminals for a function or subVI, the description of controls and indicators, the values of universal constants, and descriptions and data types of control attributes.
Histogram	A graphical summary of data in which the individual values are sorted by the range of values into which they fall (also known as bins), and in which the number of individuals falling within a each bin is counted. The data is plotted by showing the number of values (frequency) in each bin.

I

in-control process	A stable process whose variation is due only to chance causes; that is, no assignable causes of variation are present.
individual observation	A single measurement of a process characteristic.

M

matrix — Two-dimensional array.

measurement data — Data that is a result of observations or measurements of a characteristic that has a continuous range. As opposed to attribute data, measurement data is not discrete. Any discreteness in measurement data is due to the resolution of the measuring device, not the characteristic.

moving Average chart — Control chart that uses the average of *n* successive individual observations from a process to track the stability of the process mean. This type of control chart is typically used when the sample size is 1.

moving Range Chart — Control chart that uses the range between *n* successive individual observations from a process to track the stability of the process variation. This type of control chart is typically used when sample size is 1.

N

natural process limits — The limits which contain a stated fraction of the individual observations in a population. For a normally distributed population, the stated fraction is typically the process mean ± 3.0 sigma.

non-conforming unit — A unit of product or service that does not meet a specification requirement.

normally distributed — If a process is normally distributed, expected values for individuals within the process population fall on a normal or bell-shaped curve.

np Chart — Control chart that uses the number of non-conforming units in a sample to monitor the stability of the process. The sample contains *n* units, and zero or more units may be non-conforming. The value *n* can be constant from sample to sample.

O

observation — A measurement of a process characteristic.

P

p chart — Control chart that uses the fraction of non-conforming units in a sample to monitor the stability of the process. The sample contains *n* units, and zero or more units may be non-conforming. The value *n* can vary from sample to sample.

plot	A graphical representation of an array of data shown either on a graph or a chart.
pop up	To call up a special menu by clicking, usually on an object, with the right mouse button.
pop-up menu	A menu accessed by right-clicking, usually on an object. Menu options pertain to that object specifically.
Pareto chart	A chart of a set of counted or totalized characteristics in which the characteristics are ranked in order of their frequency of occurrence. In SPC, Pareto charts are normally used to evaluate relative contribution of assignable causes and prioritize corrective action.
process capability	A measure of the ability of a process to produce product within specification, assuming the process is stable. Specifically the variability that can be expected for a given process characteristic with respect to the specification limits for the characteristic.

R

R (Range) chart	Control chart that uses the sample range R to track the stability of the variation in the process. Sample range is max sample value minus min sample value. Sample size must be 2 or more.
representation	Subtype of the numeric data type, of which there are signed and unsigned byte, word, and long integers, as well as single-, double-, and extended-precision floating-point numbers, both real and complex.
run chart	A chart of the individual observations in a set of samples plotted in time order of occurrence.
run rules	Rules applied to a consecutive set of points on a control chart, that are used to detect changes in the process such as out-of-control conditions, or process shift.

S

s (std dev) chart	Control chart that uses the sample standard deviation s to determine the stability of variation in the process. Sample size must be two or more.
sample (or subgroup) size	For measurement data, this is the number of observations (or individual measurements) making up the sample. For attribute data, this is the number of units n inspected for the counted characteristic.

sample — A set of measurements (observations) or units (from which counted data is taken) used as a basis for evaluating the process.

specification limits — Limits that define the range within which a product or characteristic conforms to specification or user requirements (also known as tolerance limits).

standard values — The known standard values for process range, sample standard deviation, mean, or sigma from which control limits can be calculated.

subgroup — a set of measurements (observations) taken from a larger set.

T

tier chart — A chart in which the individual observations in each sample are plotted vertically. It is a useful means of visualizing the variation or spread in each sample.

top-level VI — VI at the top of the VI hierarchy. This term distinguishes the VI from its subVIs.

U

u chart — Control chart that uses the average number of defects per sample to monitor the stability of the process. The sample contains *n* units, and contains c defects per sample (zero or more defects per unit). The value *n* may vary from sample to sample.

V

variables chart — A pair of control charts that track whether a process is in control by tracking mean and variability of samples of measured data. Variables charts include X-bar & s, X-bar & R, x & mR charts, and mX-bar & mR charts.

VI library — Special file that contains a collection of related VIs for a specific use.

W

waveform chart — A numeric plotting indicator modeled after a paper strip chart recorder, which scrolls as it plots data.

X

x (individual) chart — Control chart that uses the individual observations from a process to track the stability of the process mean. This type of control chart is typically used when sample size is 1.

X-bar chart — Control chart that uses the sample mean, X-bar, to track the stability of the process mean. Sample size must be 2 or more.

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