PI SQC User Guide

Version 3.2

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Chapter 1

Introduction to PI SQC

PI SQC is a PI ProcessBook add-in that retrieves data from PI archives and ODBC databases, and performs statistical calculations to determine data behavior.

Results are displayed in a three-part PI SQC chart, which includes one of eight types of control charts. The PI SQC chart appears within a standard PI ProcessBook display or independent display file.

Statistical Quality Control

Statistical Quality Control (SQC) has at its heart the experience that all processes fluctuate. Fluctuations may be natural or unnatural. Natural fluctuations are generally small, while unnatural fluctuations are larger, and are introduced by external and hopefully, identifiable causes.

In simple terms:

- **Everything Varies**—People live to different ages; all patterns fluctuate.

- **Individual cases and events are unpredictable**—You cannot predict exactly how long you will live; individual points are not predictable.

- **Groups within a constant system of causes tend to be predictable**—Actuaries can use population data to predict life expectancy for insurance companies; a series of points from a constant process tend to follow a pattern.

A series of measurements of a process parameter generally will not be identical to each other. However, you can use statistical methods to establish baselines (usually called control limits) using data that represent 'good operating conditions.'

Statistically-derived control limits outline the potential behavior of a process, and permit differentiation between random fluctuations of data and true process shifts. A control limit can be defined by a specific number (center line +/- 3 standard deviations) or in terms of pattern tests (4 successive points greater than 1.5 standard deviations from the center line on the same side of the center line).

The primary method of process evaluation is a control chart, a graphic comparison of process data versus calculated control limits. You can use a control chart to detect process variations that have definable causes by highlighting instances where process data runs outside the control limits.

SQC in the Process Industry

Product specifications typically are market-based, and an actual process is capable of performing to tighter tolerances. SQC is one approach to maintaining and improving quality.

SQC identifies instances of unnatural fluctuation so that causes can be assigned and corrected. Control charts are employed by a wide range of industries and agencies as a means to monitor and stimulate improvements in many types of processes.

In many industries, SQC has been applied with large economic benefits. However, applications of SQC methods have been limited by the daunting and often tedious tasks of calculating samples and plotting data, especially when dealing with very large data sets.

SQC in PI ProcessBook

PI SQC appears appears as an icon on the PI ProcessBook toolbar. To add an SQC chart object to a ProcessBook display:

1. In Build mode, click the **SQC** icon and drag in the workspace to add the object.

    The **PI SQC Chart Definition** dialog appears.

2. Configure chart settings and click **OK**.

3. Return to Run Mode.

As a dynamic object, PI SQC operates like to other dynamic symbols in PI ProcessBook displays. When you select an SQC symbol and view the **Details** window in ProcessBook, you see a tabular view of the data used to create the SQC chart.

For event-based SQC charts based on PI points, you can also create annotations for individual event values when *Data* is selected in the **Data Source** drop-down list. If sample filtering is used in the chart, annotation is disabled for any rows that display the *Filtered* indicator.

Data Retrieval and Calculation

Once a PI SQC chart is configured, PI ProcessBook retrieves fresh data whenever you open the display containing the chart. The time stamp of a PI tag, a specified number of data points, or a change in a Trigger Tag can also trigger a query. Sampling is either time- or event-based.

SQC performs calculations when data is retrieved (including any *PI SQC-RT* (page 3) calculations required remotely), and then updates chart values. The same events occur when you modify properties of the SQC calculation or chart, allowing you to instantly view and analyze changes.

If the end time of a PI SQC chart is configured as the current time, PI SQC refreshes the chart whenever there is a new chart tag value recorded in PI or ODBC data sources.

PI SQC-RT

PI SQC-RT is a separately-licensed enhancement to the standard PI Alarm Subsystem. PI SQC-RT generates SQC Alarm tags, which combine source tag values with the results of real time SQC pattern tests performed on the source tag.

A PI SQC alarm requires five PI tags in addition to the alarm tag itself. These tags provide:

- a data source for the alarm
- user control over the operation of the alarm tag
- storage of control limits

PI SQC-RT alarms can be plotted and visualized through the PI SQC add-in. See the *PI SQC-RT User Guide* for more information.

Chapter 2

PI SQC Chart Components

A PI SQC chart includes several components:

- A control chart on the bottom
- A *histogram* (page 8) at top left
- A *legend* (page 9) at top right
- *Four sheets of data and statistics* (page 9), accessible when you click the chart title
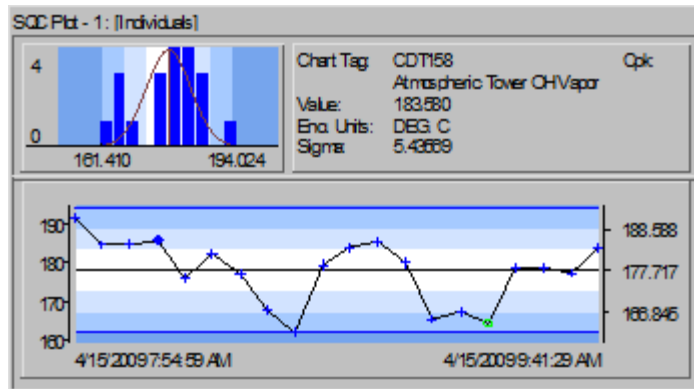
You may configure the control chart, the histogram, and the legend in a variety of ways, and any component may be omitted.

Control Chart

A control chart shows a curve of data markers representing sample values plotted across time:

- The left axis displays evenly spaced labels in the engineering units of the source tag.
- The right axis displays control limits.
- The horizontal axis displays evenly spaced data markers.
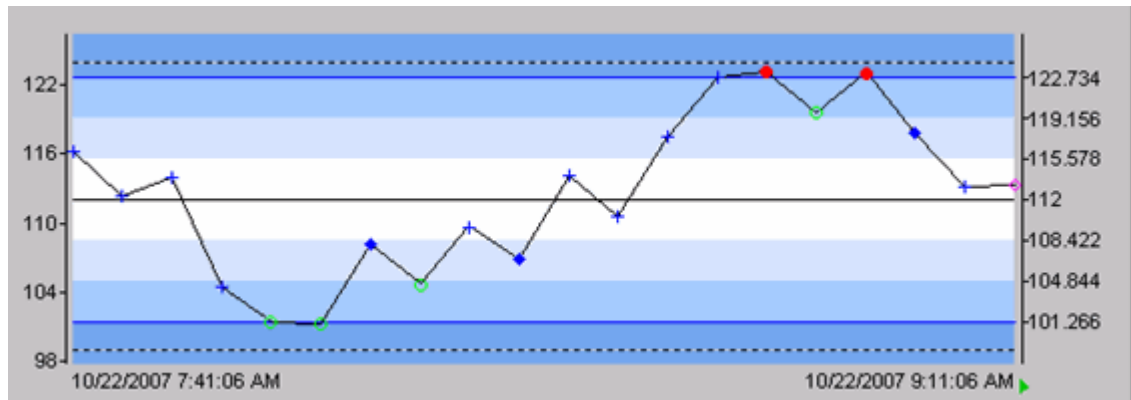
The left and right timestamps on the horizontal axis represent the first and last plot values. Each plot point on a control chart is equidistant from preceding and succeeding points, regardless of the time span between them.

If a sample value plots outside of the control limits, an alarm condition occurs and data markers appear in different colors and shapes. Data markers are not displayed if they overlap; only alarm markers appear.

A green triangle at lower right indicates the PI SQC chart is being updated in real time.

Control Zones

Control charts include colored horizontal control zones and a target or center line. The colors match the control limits on the right axis and in the *histogram* (page 8).

Zones are determined by *control limits* (page 21) for process evaluation, which may be established in several ways:

- Specified by a user

- Calculated from actual point values

- Calculated remotely by a PI SQC-RT Alarm tag

The zones represent standard SQC classifications:

Center Zone	The area between -1 and +1 Sigma of Center Line.
One Sigma Zone	The area between -2 and -1 Sigma of Center Line and the area between +1 and +2 Sigma of Center Line.
Two Sigma Zone	The area between -3 and -2 Sigma of Center Line and the area between +2 and +3 Sigma of Center Line.
Outside 3 Sigma Zone	The areas outside control limits.

Note: For Range, Moving Range, Standard Deviation, and Moving Standard Deviation charts, the upper and lower zones may be different in size because the *Sigma* (page 7) values may differ.

Sigma

Since the target for Range, Moving Range, Standard Deviation, and Moving Standard Deviation charts is not always centered on the chart, upper and lower Sigmas may differ.

Sigma should be interpreted in Range and Standard Deviation charts to mean 1/3 the distance between the center line and the upper or lower control limit. For instance, +2 Sigma refers to two-thirds of the distance between the center line and the upper control limit.

The most applicable pattern test for Range and Standard Deviation charts is the 3-Sigma test, which indicates data points outside or on the upper or lower control limits.

Note: The lower control limit in Range and Standard Deviation charts is always zero for sample sizes smaller than 7 and 6, respectively.

Alarm Status

A control chart displays a marker for each data point. If a point is in an *alarm condition* (page 23), an alarm marker is substituted. If a data point falls outside of the vertical plot range, its marker is displayed at the top or bottom of the control chart.

PI SQC-RT (page 3) may also be used to configure alarms on the PI Server, and which appear in a control chart. A selected data point is in alarm status if it meets a pattern test condition:

- A green dot ● indicates no pattern test conditions have been met.

- A red exclamation point ❗ indicates a pattern test condition has been met.

To view alarm tag details in a control chart:

- Move the mouse over a data point until a magnifier cursor appears, and click on the left mouse button.

  The Alarm Details dialog appears. The Alarm Details dialog lists the timestamp, value and alarm status of a selected data point.

  Note: The Alarm Details dialog is disabled when *trend cursors* (page 8) are activated.

If SQC alarms are configured to use the optional test status tag, you can right-click a marker in an alarm state to view pass/fail status for all configured pattern tests. If you do not use the optional test status point, then only the highest precedence pattern test failure is displayed.

For information on how to configure PI SQC-RT Alarm tags, refer to the *PI SQC RT User Manual*.

Trend Cursors

In PI ProcessBook **Run Mode**, trend cursors can be added from the left edge of a control chart to read sample values across the chart. Add a second cursor to compare values across a range.

To add trend cursors:

- Click the Trend Cursor button ⊟ on the toolbar to add a cursor to the right edge of the chart.

    When released, a trend cursor remains in one spot. Click and drag a cursor to move it to a different spot.

Histogram

The **histogram** component of a PI SQC chart is a bar graph of the frequency distribution of plot data.

The horizontal scale spans the Center Line minus five Sigma to the Center Line plus five Sigma. The scale is marked at +3 Sigma and -3 Sigma from the center line. The resulting zones are colored using the same colors in the control chart.

The Mean, Upper and Lower Specification Limits are also indicated in the histogram.

The number of bars is configurable, and from 1 to 100 bars may be displayed. The vertical scale runs from zero to the maximum number of samples per bar.

A *normal distribution curve* (page 9) is drawn in the histogram based on the sample mean and the standard deviation of the sample.

To specify the number of bars or to change the appearance of the histogram, use the *Format tab* (page 25) of the **PI SQC Chart Definition** dialog.

Distribution and Standard Deviation

If you specify *control limits* (page 21), the Sigma that is used in the normal distribution curve is calculated by 1/3 the distance between the center line and each control limit.

You may specify uneven control limits, that is, the distance of the upper control limit from the center line may be different from the distance of the lower limit from the center line. In such cases, the normal distribution curve reflects Sigma values obtained by:

$Sigma_{upper}$ = (Upper Control Limit - Center Line) / 3

$Sigma_{lower}$ = (Center Line - Lower Control Limit) / 3

Legend

The **legend** appears at top right in a PI SQC chart, and may display the following information:

Item	Description
Chart tag	The name of the tag providing raw data to the chart
Trigger Tag	The name of the tag used to *trigger a new sampling* (page 16)
Value	The current value of the *Chart Tag* (page 14)
Engineering Units	Engineering units for the Chart Tag
USL/LSL	Upper and lower specification limits
Sigma	Sigma as used in calculating upper and lower control limits
Cpk	*Process Capability Index* (page 40), a calculation based on specification limits.

Items that do not have a current value are not displayed. For example, if a user does not configure *specification limits* (page 21), the USL/LSL is not displayed. Calculated items such as Cpk or Sigma that do not have a current value will display N/A if they are selected to show on the legend.

To change the appearance of the legend, use the *Format tab* (page 25) of the **PI SQC Chart Definition** dialog.

Data Sheets

Four data sheets are available for each PI SQC Chart. To see the data sheets:

1. Go to **Run Mode** and double-click the title of the chart.

   The Statistical Quality Control Details dialog appears.

2. Use the **Options** menu to select any data sheet.

Statistical data are provided in double-precision numbers. Click **Save Data to File** to save all four pages as a text file.

Statistics Sheet

Eight statistical values are calculated for control chart plot data each time a PI SQC chart updates:

Statistic	Description
Mean	Average value of plot data
Median	Median value of plot data
Mode	Most frequently occurring value of plot data
STDEV	Standard deviation of plot data
Cpk	Calculated Process Capability Index (*Cpk* (see "Process Capability Index (Cpk)" on page 40)), based on specification limits for plot data
Max	Maximum value of plot data
Min	Minimum value of plot data
Sigma	Sigma of the samples as used in upper and lower control limits

Raw Data Sheet

The Index column identifies each raw data point plotted for the chart tag, followed by Timestamp and point Value. The Status parameter (sometimes called IStat) depends on the tag's Point Type in PI.

Plot Data Sheet

The Index column identifies plotted data points, followed by Timestamp and Value. Following are columns for each *control parameter* (page 21), which may vary over time.

The Alarm column indicates whether a data point has triggered an alarm or exceeded 1 Sigma from the center line.

Control Limits Sheet

Specifications and calculated or specified control limits are listed.

PI SQC Chart Definition Dialog

The PI SQC Chart Definition dialog is used to define parameters and construct various types of SQC charts.

Note: For calculated tags from PI for Open VMS Server, much of the definition functionality is disabled and only Alarm and Format properties can be modified.

Build a PI SQC Chart

When designing a PI SQC chart, keep in mind that you are simultaneously creating and structuring a query to retrieve the desired tag and SQC data.

If the resulting PI SQC chart is not populated with appropriate data, the query has failed and the you may receive a message such as "Event- based query failed" or "Not enough data points." Review your selections in the Chart Definition dialog until your PI SQC chart appears correctly.

To build a new PI SQC chart:

1. Open a ProcessBook display or an independent display file.

2. Select the **PI SQC Chart** tool on the toolbar or choose **Draw > SQC Chart**.

    The cursor changes to an arrow with a small SQC label.

3. Click and drag to define the bounding rectangle for the chart within the display.

    Once the bounding rectangle has been defined, the **PI SQC Chart Definition** dialog appears.

4. Define the chart using the six tabs of the *PI SQC Chart Definition dialog* (page 11).

Edit a PI SQC Chart

To modify an existing PI SQC chart:

*   In **Build** mode, double-click anywhere in the PI SQC Chart to bring up the *Chart Definition dialog* (page 11).

*   In **Run** mode, click the **Item Definition** button to display the *Chart Definition dialog* (page 11).

General Tab

The General tab resembles the PI ProcessBook Trend Definition dialog and is used to specify basic chart parameters.

Chart Title

Enter a distinctive title for the PI SQC Chart. The default is SQC Plot -1.

Chart Type

Select the type of control chart you want to display. The name of the chart type is included in square brackets after the control chart title.

Each control chart presents a different view of sample data, and represents different *mathematical calculations* (page 27) based on the type of plot, sample size, and other factors.

The eight available control charts and their properties are described in the following sections.

Individuals Chart

An Individuals chart plots raw data from PI or an ODBC dataset, and utilizes single observations rather than sample groups to evaluate the stability of the process.

An Individuals chart is used when it is impractical to calculate the average of a group of measurements. Individuals charts are typically used in conjunction with Range or Moving Range charts to detect variability.

In Individuals charts, sample size must be equal to 1, and the center line is the process mean. The Moving Range is used to estimate standard deviation when calculating control limits. If a PI tag is used as the upper (USL) or lower specification limit (LSL), the control chart displays USL and LSL traces.

Note: Measurements are not independent of one another in an Individuals chart. Pattern tests are therefore not applicable, and only the points outside of control limits should be considered significant.

X-Bar (Average) Chart

An X-Bar or Average chart calculates the average of a subgroup of data, and plots it against other sample averages. The sample mean is used as the center line unless otherwise specified. Individual measurements are assumed to be independent.

An X-Bar chart indicates where a process is centered, and provides information about the quality of process control. Fluctuations that directly affect the X- Bar chart display can be construed to affect all parts of the product at once, and in the same general manner.

Averaging data tends to reduce the effect of random error associated with the variability due to measurement and inherent process variation. Averages can be more sensitive in revealing changes in process level than individual observations.

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Moving Average Chart

A Moving Average chart calculates averages inclusive of each new individual measurement, *n*, and plots them against previous *n- 1* averages.

Moving Average charts have the advantage of being able to detect process shifts and dampen out random errors on individual measurements, and are useful when taking more than a single observation per sample is impractical.

In evaluating a Moving Average Chart, consider only whether data is within 3 sigma. Moving Average charts should be used in conjunction with the Moving Range chart.

Two disadvantages of Moving Range charts are:

- A lag effect due to sample measurements derived from *n-1* previous measurements.

- Oscillatory effects that occur due to successive samples having correlated random error.

Sample size cannot be less than 2 in Moving Average charts.

Exponentially Weighted Moving Average (EWMA) Chart

An EWMA chart is an exponentially "smoothed" moving average used for evaluating the stability of a process. The term "exponentially" refers to the method that is employed to average earlier data with current data.

A *Lambda* (page 19) factor is used to associate a weight with each new data point, compared to the remaining data points in the designated sample size. This exponential weighting is applied to each data point, whether individual observations or subgroup averages, and has the effect of reducing the contribution of older data through progressively smaller weights.

The EWMA chart can be used in place of a Moving Average chart to place more emphasis on current data values. Placing more emphasis on current data makes the EWMA chart more sensitive to small process trends and less sensitive to sudden process spikes.

Note: The Lambda weighting factor is typically between 0.2 and 0.5, with a default value of 0.5.

Standard Deviation (s) Chart

A Standard Deviation chart calculates and plots a sample standard deviation for each sample subgroup. A Standard Deviation chart serves the same purpose as the Range chart, but should be used when the sample size is greater than 8.

Note: Sample size must be greater than 1, and preferably equal to or greater than 10, the default sample size.

Moving Standard Deviation Chart

A Moving Standard Deviation chart utilizes the latest *n* observations to judge the stability of the process. The current sample standard deviation is calculated by replacing the oldest value in the sample with the current value.

Moving Standard Deviation charts are used instead of Moving Range charts when the sample subgroup size is greater than 8. As with Moving Average charts, the effect of combining successive data points causes correlated contributions of random error and results in an oscillatory effect when plotted.

Range (R) Chart

A Range chart calculates the range (maximum - minimum) within each sample to determine the stability of a process. Calculated ranges are used to estimate process variability due to chance causes over short time spans.

For example, a valve linkage in need of repair does not move the same way each time it is told to move. This inconsistency in valve action affects the product differently at different times, and might be examined through a Range chart.

A Range chart is always evaluated in conjunction with either an Individuals chart or an Average chart. *Sigma* (page 7) values may be interpreted differently for range charts.

Note: Range charts are not recommended for sample sizes larger than 8, and require a sample size greater than 1, with a sample size of 2 as the default value.

Moving Range (Rm) Chart

A Moving Range chart uses the latest *n* observations to judge the stability of the process. The current range is calculated by replacing the oldest value in the sample with the current value.

As with Moving Average charts, the effect of combining successive data points causes correlated contributions of random error and results in an oscillatory effect when plotted. *Sigma* (page 7) values may also be interpreted differently for range charts.

Note: Moving Range charts are not recommended for sample sizes larger than 8.

Chart Tag

Enter the name of the source tag to plot in the chart. The **Chart Tag** specifies the process data being plotted. Tag names or data sets that define PI SQC limits or parameters are defined on another tab.

You can enter this tag manually or select the tag from PI through a **Tag Search**. Tag names returned from a Tag Search appear with an appended server name (`\\server\tagname`) in the **Chart Tag** box.

> **Note**: The **Chart Tag** field must be filled before you can switch to another tab.

The **Chart Tag** field is also used for *PI SQC-RT* (page 3) Alarm tags, which are configured at the PI server level (where the point class is SQC_Alarm). Click **Alarm Tag Attributes** to view the attributes of an Alarm tag.

The query that retrieves *Chart Tag* (page 14) values also retrieves the point attributes shown below:

Point Attribute Name	Usage
Descriptor	Displayed in the Legend
Point Type	Used in calculations not displayed
Zero	May be used as lower plot limit
Span	Defines data range as vertical scale
Starting digital state	Digital zero
Number of digital states	Number of possible digital states minus one.
Engineering units	Displayed in the Legend

Tag Search

A PI tag search allows you to search all connected PI Servers for tags meeting a given a set of criteria, such as one ore more tag attribute values.

- Click **Tag Search** to search a PI Server for tags using the **Tag Search** dialog.

You can select tags from a Search Results list. The first tag selected is added to the **Chart Tag** field with server name will be included.

PI SQC uses ODBC data sets and custom placeholders in the same manner as PI ProcessBook trends. You can use an alias or property value, or a dataset in place of a tag.

- Click the adjacent arrow button and choose a PI Calculation or ODBC Data Set from the menu to search other data sources using a corresponding **Data** dialog.

  If an ODBC Data Set is selected then the SQL query must contain the time placeholders "Start Time" and "End Time" in the ODBC dataset to return the time frame specified in the SQC chart definition.

  If a dataset includes default placeholders, you can click **Custom Placeholders** to supply values for variables used in the ODBC query.

- Choose Module Context to select aliases or properties via a module context defined in a PI Module Database.

Scale

Use **Scale** group fields to set the minimum and maximum for the chart's two vertical scales. Scales are based either on data values, explicit limits, or standard deviation calculations. The center line (or target) is the mean value of the plot data.

The following scale options are available:

- **AutoRange** (the default), which automatically sets chart limits at even numbers near the minimum and the maximum of plotted values.

- **Database** (for PI tags only), which uses the zero and span attributes of the PI SQC tag plotted.

  Zero and span are parameters configured in PI and cannot be changed locally.

- **Center Line +/- X Engineering Units**

- **Center Line +/- N Sigma**

- **Center Line +/- 3 Sigma**

- **Center Line +/- 4 Sigma**

- **Center Line +/- 5 Sigma**

- **USL/LSL**, which uses upper and lower specification limits.

- **Absolute Eng. Units**, which allows manual entry of maximum and minimum scale values.

Plot Time

The plot time refers to the range of time over which the data is plotted and SQC calculations are assessed.

Several **Start Time** options are available:

- Standard PI time relative expressions, measuring time in multiples of hours and days from the present time, *.

- **Samples Before End Time** allows you to specify a number of samples previous to the **End Time**, using a field that appears below the **Start Time** field when this option is selected. Select or input an integer for the number of samples. The default value is 20.

  In **Run** Mode, a PI SQC chart pans across values by the number of samples defined when stepping forward or backward through time.

- **Trigger Tag Change** indicates that the start of each plot and product run is defined by the first data point that occurs after a specific trigger tag changes value. Use the field that appears below the **Start Time** field when this option is selected to enter a tag name, or click the ellipsis button next to the field to run a tag search.

  In **Run** Mode, the PI SQC Chart pans across values based on instances in time when the **Trigger Tag** value changes. All three parts of the chart are recalculated when the value is updated.

  On the control chart, the timestamp defining the left end of the horizontal scale represents the first value derived after the trigger tag value changes, indicating the start of a product run.

  The plotted point at the right end is either the last value before the current time (for real time data), or the last plotted value before the specified end time of the plot and product run.

> **Note**: The time of a trigger tag change does not equate to the start time of a sample, but instead determines which data point demarcates the first point of a sample group. The start time of the actual sample is defined on the **Sample** tab and occurs after the trigger tag change. If the time range or its display is changed, the new end time is used to determine the time of the previous trigger tag change.

End Time is defined using standard PI time relative expressions, measuring time in multiples of hours and days from the present time, *.

For charts that end at the current time, whenever a PI tag value changes or a new measurement is received from an ODBC data set, data is recalculated and both the control chart and histogram are updated.

Sample Tab

The **Sample** tab defines how chart tag samples are calculated.

Sampling Method

Two methods can be selected to work raw data into packets for calculating samples:

Event-based sampling

Event-based sampling is depends on a sample size n, where every n raw data points are combined in a statistical calculation to produce a single sample.

For moving-window event-based calculations, a sample is produced from the raw data array, R, by using R_i through $R(n+i)$.

Time-based Sampling

Time-based sampling is used only for PI data. This method organizes data into calculation packets by working with four parameters:

Parameter	Definition
Start Time (page 19)	This time stamp adjusts the start time of the samples.
Calculation Period (page 19)	Duration of time between the start of sampling periods.
Sample Period (page 19)	Time between samples within sample group.
Sample Size (page 18)	The count of raw data points used in the sample calculation

Sampling begins at the Start Time and continues with samples calculated every Calculation Period. Within a Calculation Period, the first n samples spaced evenly by the Sample Period are used for calculation.

For an *EWMA* (page 13) chart, a sample is produced for the first calculation period (the window), then the window is moved forward one sample period in time, and the next calculation made.

Note: An ODBC data set without a time column does not display a time stamp on the horizontal axis of a control chart.

Calculation Basis

Calculation Basis options define the mathematical parameters used for sampling.

- A **Time**-based calculation uses samples for every **Sample Period** and performs a calculation for every **Calculation Period**, determined whenever samples matching the **Sample Size** are collected.

- An **Event**-based calculation uses every raw data value associated with the tag. For event-based calculations, **Calculation Period**, **Sample Period**, and **Start Time of Sample** are disabled.

Note: Calculation Basis information is not available for PISQC-RT Alarm Tags.

Check Settings

Click **Check Settings** to test time settings for **Time**-based samples and ensure the minimum sample size once you have specified all the necessary parameters for your calculation basis.

Sample Size

The **Sample Size** is the number of measurements grouped into one sample.

Samples should be chosen such that each sample encompasses all the random variation inherent in the process. A sampling scheme that meets this criterion is said to produce rational subgroups. Provided samples are aligned with rational subgroups, the smaller the sample size, the more sensitive calculations are to process changes.

For new charts, the minimum sample size is the default size. The following minimum and recommended maximum values apply to sampling:

Chart Type	Default/ Minimum	Recommended Maximum
Individual	1	--
X-bar or Average	2	--
Moving Average	2	--
EWMA	1	--
Range	2	8
Moving Range	2	8
Standard Deviation	8	--

Chart Type	Default/ Minimum	Recommended Maximum
Moving Std. Deviation	8	--

Calculation Period

For **Time**-based calculations, the **Calculation Period** is the time interval between the start of sample groups. The time period must be entered in the form:

    hh:mm:ss

where **hh** is hours, **mm** is minutes, and **ss** is seconds.

Calculation Period is ignored for **Event**-based calculations.

Sample Period

For **Time**-based calculations, the **Sample Period** is the time between samples within a sample group. The product of the **Sample Period** and the **Sample Size** should be less than or equal to the **Calculation Period**.

For example, if the **Calculation Period** is 2 hours, the **Sample Period** is 10 minutes, and the **Sample Size** is 5, the sample groups would begin at midnight, 2:00, 4:00, and so on. The samples for the midnight sample group would be at 12:00, 12:10, 12:20, 12:30, and 12:40. The samples for the next group would be at 2:00, 2:10, 2:20, 2:30, and 2:40.

Start Time of Sample

Use **Start Time of Sample** to adjust the start time of a sample within a day. If the **Calculation Period** is greater than one day, the **Start Time** is used for the day on which the calculation is started. The derived values are calculated and stored at the time of the last sample within the **Calculation Period**.

For example, if the **Calculation Period** is 2 hours, the **Sample Period** is 10 minutes, the **Sample Size** is 5, and the **Start Time** is 3 a.m., then sample groups begin at 3 a.m., 5.a.m., and so forth. Samples for the first sample group would be taken at 3:00, 3:10, 3:20, 3:30, and 3:40.

Time Stamp at

Specify the raw data point to use in determining a timestamp for each calculated point. This feature is useful when the **Sample Size** is larger than 1.

For example, if the sample size is 5 and **Time stamp at** is set to 3, the time at which every third raw data point is collected is used as the timestamp for the related calculated point.

Lambda

Lambda associates a weight with each new data point as compared with the remaining data points in the designated sample. The **Lambda** factor pertains only to *EWMA* (page 13) (Exponentially Weighted Moving Average) charts, and does not appear for other types.

Lambda must be between 0 and 1. A smaller value of **Lambda** provides greater smoothing effects and the resulting chart will emphasize trends as opposed to point-to-point fluctuations. The default value for **Lambda** is 0.5, with values between 0.2 and 0.5 most typical.

Filter Equations

Filter Equations can be used to filter data from samples. In a filter equation, 0 equals FALSE and 1 equals TRUE. Only data representative of time periods when the **Filter Equation** is TRUE are included in samples and used in PI SQC calculations.

Note: Filter equations can include PI tags, but not ODBC data sets. However, you can filter ODBC data using the WHERE clause of the ODBC query.

Use the following tools to build a filter equation in the **Filter Equation** field:

- Click **Tag Search** to locate PI tags and append the selected result to the equation in the **Filter Equation** box. For multiple selected items, only the first is added.

  PI tags used in a filter equation must exist on the same PI server as the *Chart Tag* (page 14).

- Click **Check Syntax** to send the equation to the PI server to validate *syntax* (page 20). A dialog box indicates any errors in the equation syntax.

  The contents of the **Filter Equation** field are also validated whenever you exit the **Sample** tab.

- Clear the **Keep Bad Values** checkbox to omit *bad data values* (page 21) from samples and from control limit calculations.

Filter Equation Syntax

Filter equations use PI Performance Equation syntax and may include:

- operands
- arithmetic operators
- built-in functions
- user-defined formulas
- if-then -else structures
- PI tag values

Filters may cause large time gaps in data. To avoid gaps you may choose to *keep bad values* (page 21).

Note: When defining a filter equation, use PI tags with the step attribute set to TRUE. Interpolation of tag values in the filter expression might otherwise provide a misleading visualization.

Keep Bad Values

The number of plot markers in a time series is the number of good values divided by sample size. If they do not divide evenly, the remainder is ignored. For example, given a sample size of 10 and 99 good values, a plot will have 9 points.

You may choose to keep bad values in control charts, allowing PI tag values with invalid status to be included in sample groups (but not in calculations). In such cases, the chart is calculated using only the remaining good values.

If bad values are kept, they are counted when creating sample subgroups for averages, ranges, and so forth. The number of markers is then the total number of values (good and bad) divided by the sample size, with any remainder ignored.

If bad values are not kept, but rather omitted from the time series of values, all samples are the same size.

For example, if **Keep Bad Values** is checked, and if the sample size is 5 and if a group of 5 data points includes one bad point, only 4 values will be used for the calculation for this particular plot point.

PI values that fail the criteria are plotted with a black dot on the Shewhart chart. If a consecutive group of values fail the filter criteria, only the first PI value to fail is plotted; repeated consecutive failures are omitted from the sample.

An entire sample calculation is determined to be bad, and is not plotted, whenever the number of good values is less than 50% of the specified sample size. The Range and Moving Range calculations are exceptions in that they require only 2 good values in a sample subgroup.

Note: For EWMA charts, a bad value resets the calculation. If $EWMA_t$ is bad, $EWMA_{t+1} = x_{t+1}$.

Control Parameters Tab

Control parameters are process limits, which may either be process specifications or control limits.

- Process specifications are fixed, "not to exceed" limits applied to a product and based on market, safety, or engineering limits.

- Control limits are calculated from measurements sampled during a controlled process operation, or from the actual data of the current process.

Note: For PI SQC-RT Alarm Tags, control limits are read-only. Refer to the *PI SQC-RT User Guide* for information on remote calculation of control limits in PI.

All PI SQC control limits used to define *control chart zones* (page 6) are accessible through the **Control Parameters** tab. You can select constants, PI tags, or ODBC data sets to define limits for each parameter:

- Enter constant values directly in **Control Limit** fields.

If constants are used, then the control limits do not change unless the user returns to the **Control Parameters** tab and manually changes them.

- Click **Tag Search** to use the **Tag Search** dialog to find and select PI tags. Corresponding tag values are used as control limits.

- Click the arrow button adjacent to **Tag Search** and select **PI Calculation** or **ODBC** to display a corresponding **Data** dialog. Then choose a dataset that contains the desired control limit values.

  If an ODBC data set is used for limits, you must specify Start and End Times under *Plot Time* (page 16). The *PI ProcessBook User Guide* includes information on how to create a new ODBC data set.

- Click the arrow button and select **Element Context** to select an AF Element as a control limit.

  Note: this option only appears if you use PI SQC with PI ProcessBook 3.2 or higher.

- Click one of the **Sigma Calculation Method** options:
  o Average Range Estimate
  o Average Standard Deviation Estimate

  When a new SQC symbol is created through the user interface or automation, the default values of the Sigma Calculation Method vary according to the plot type. The plot type also determines if the **Sigma Calculation Method** option buttons are disabled or non-modifiable through automation. These buttons are also disabled for server side alarms, regardless of plot type.

You may also let PI SQC calculate limits based on the data in the plot:

- If you do not specify a **Center Line** value, PI SQC uses the mean of the plot data as the center line.

- If you do not specify any control limit parameters, PI SQC calculates limits based on a Sigma value, determined by the distribution of data.

Data Filter Tab

Data filters allow removal of data that do not represent a nominal process. Data that do not meet the specified criteria are discarded, and standard deviation, process capability, mean, and all other statistical calculations are then made with the remaining data.

Statistical calculations are generally computed at the end of the defined time period governed by a *trigger tag* (page 16). The defined time period is always the time period between the left and right axis of the chart.

Note: For PI SQC-RT Alarm Tags, Data Filter information is not available.

Sigma Calculation Data Filter

A **Sigma Calculation Data Filter** provides logic that determines how the system analyzes and discards data prior to performing statistical calculations.

- Enter a **Minimum data points** value to specify the threshold required for a valid Sigma calculation.

  This value is required, and should depend on the sample size and the particular operating environment. The default is 10 and the value must be an integer.

- When selected, the **Eliminate samples** option eliminates data outside of a specified number, **n** Sigma.

  Generally, **n** is set to a value between 4 and 7. The default is 5, and **n** must be an integer greater than one.

Transition Data Filter

The **Transition Data Filter** allows you configure the trigger tag to specify when calculations should begin after a new trigger tag event occurs. The complete configuration sentence (with default values) reads,

```
After trigger tag event, begin calculating when 5 consecutive
samples within 3 Sigma of each other are reported.
```

Four variables in the filter statement are configurable:

- Number of samples (default is 5)

- Consecutive or non-consecutive samples

- Range by which two data points can be separated before calculation resumes (default is 3 Sigma)

- Variability around either the center line or between samples, to indicate the relationship data points must share (default is `Each Other`, indicating relationship between samples)

You may also force the system to ignore the filter statement entirely by setting the number of samples variable to 1.

Use the check boxes to specify if the **Transition Data Filter** should apply to Sigma calculations, to alarm calculations, or to both.

Alarm Tab

The **Alarm** tab provides tools to define *pattern tests* (page 24) for unnatural data variation, and to indicate process points that are out of statistical control. PI SQC applies pattern tests and calculates an alarm state for each sample. Points out of statistical control can be configured to display with specific symbols and colors in the control chart.

> **Note**: For PI SQC-RT Alarm tags, **Alarm** tab settings are read-only (except alarm marker type and alarm marker color).

The **Alarm** tab includes criteria and settings for seven SQC pattern tests, in order of highest precedence:

- **Outside Control** – A count of the number of data points outside the control limit on one side of the centerline.

- **Outside Two Sigma** – A count of the number of data points outside a limit drawn two-thirds of the distance between the centerline and a control limit.

- **Outside One Sigma** – A count of the number of data points outside a limit drawn one-third of the distance between the centerline and a control limit.

- **One Side of Centerline** – A count of the number of data points on one side of the centerline.

- **Stratification** – A count of the number of data points that fall within the upper and lower one sigma limits on both sides of the center line

- **Mixture** – A count of the number of data points that fall outside the upper and lower one sigma limits on both sides of the center line.

- **Trend** – A count of the number of data points, which are monotonically increasing or decreasing.

To configure pattern tests:

- Click the checkbox at left to enable a test.

- Click the marker symbol in the next column and choose **Marker** to reset the marker shape, or **Color** to reset the marker color through the Windows color palette.

  The marker format appears against zone backgrounds set on the *Format tab* (page 25).

- Enter values to describe the test conditions in the two entry fields to complete the test test condition.

Alarm Reset

You may also specify an **Alarm Reset** tag by clicking the ellipsis button and using the **Tag Search** dialog to select a PI tag. When the specified tag reaches zero, alarm calculations are stopped.

When the **Alarm Reset** tag is no longer zero, alarm calculations restart. If no reset tag is specified, alarms are always on by default.

Pattern Tests

Alarm pattern tests compare derived values to control limit lines, center line and intermediate values. The simplest pattern is a test for a single value outside of control limits.

Control charts are more sensitive to process changes when more complicated tests are used. Such tests use a sequence of values to test for patterns that are unlikely in a normal

distribution. For example, an out-of- control condition for charts may be when 2 out of 3 consecutive values are outside of 2 Sigma.

Default settings for pattern tests are based on recommendations from the *Statistical Quality Control Handbook*; Western Electric Co., Inc.; 1956; Indianapolis, Indiana, on pages 23-30, under "Tests for Unnatural Patterns."

Format Tab

The **Format** tab provides tools used to modify the appearance of SQC charts. As you make changes in the Format tab, the sample chart at the lower right of the tab changes to preview your selections.

Chart Element

Select an element and use the accompanying options to specify **Line Style** and **Width**, **Data Markers** and their **Size**, and the **Color** of the selected element:

- **Center Zone** - 0-1 Sigma above or below the center line
- **One Sigma Zone** - between 1-2 Sigma above or below the center line
- **Two Sigma Zone** - between 2-3 Sigma above or below the center line
- **Outside 3 Sigma Zone** - 3 Sigma above or below the center line
- **Text** - on all parts of the chart. The font size and font style are configurable using the PI ProcessBook font toolbar button.
- **Background** - color of the chart background
- **Control Chart Data** - pen color and line style for the curve plotted on the control chart
- **Specification Limits** - pen color and line style for USL/LSL
- **Histogram Bars** - color of histogram bars
- **Histogram Distribution** - pen color and line style for the curve plotted on the Histogram
- **Marker** - shape and color of the data markers that are not in alarm. A value of `None` causes all markers to disappear.
- **Histogram Specs** - pen color and line style for specification lines on the histogram
- **Histogram Mean** - pen color and line style for the mean on the histogram
- **Control Limits** - pen color and line style for the UCL and LCL on the control chart

Chart Options

The check boxes in the **Chart Options** group designate whether or not to display the following items in the PI SQC chart:

- Chart Title
- Histogram
- Legend
- Control Chart

- Control Limit Scale
- Plot Limits Stepwise

Legend

The **Legend** group check boxes designate whether or not to display the following items in the chart legend:

- **Chart Tag** - the name of the *chart tag* (page 14)
- **Trigger Tag** - the name of the *trigger tag* (page 16), if used
- **Eng. Units** - the engineering units associated with the chart tag
- **USL/LSL** - upper and lower specification limits
- **Value** - the current value of the chart tag
- **Sigma -** the sigma value of control limits
- **Cpk** - the *Cpk* (see "Process Capability Index (Cpk)" on page 40), based on the current plot

Zone Colors

Zone color samples appear at the upper right of the tab, below shape and color samples of data markers used for points in alarm (as defined on the *Alarm tab* (page 23)).

Zone colors are set with other Chart Element controls, but you can make final adjustments to alarm markers using the data marker buttons.

Histogram Bars

Defines the number of bars to be included in the *histogram* (page 8).

Save as Default

To retain your format settings as the default formatting for future charts, click the **Save as Default** button below the **Chart Options**. The settings are stored in the *Procbook.ini* file until they are saved again.

Statistical Calculation Basis

These general conventions apply to statistical calculations:

- For PI tags, data precision is set to a tag's display precision property in PI. For ODBC data sets, precision is set to 5 significant figures.

- If a center line is not specified for a chart, the grand average of data is used instead.

- Either a constant or PI tag may be specified as a control limit. If control limits are not specified, theoretical control limits are calculated from available data using the ANSI/ASQC standard A1-1987.

- Control limits are calculated separately to allow control limit bands of different heights.

The statistical analysis methods used by PI SQC are based on concepts and equations from *Essentials of SPC in the Process Industries* by James M. Pruett and Helmut Schneider, Second printing, February 1996, and the ANSI/ASQC standard A1-1987.

Control Chart Calculations

The following sections detail the calculations used in plotting PI SQC control charts. Statistical formulas presented in this section refer to *constants* (page 36) and *symbols* (page 39) described in corresponding topics.

Individuals Calculations

Sample Average

The sample average value is calculated using the equation:

$$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n}$$

where:

X_i are individual measurements

n is the number of measurements

Control Limits

The three sigma control limits for Individuals charts are:

$$UCL = \bar{X} + 3\sigma$$
$$LCL = \bar{X} - 3\sigma$$

where:

UCL is the Upper Control Limit

LCL is the Lower Control Limit

$\bar{X}$ is the sample average as calculated previously

σ is the process standard deviation, also known as sigma

The process standard deviation is estimated using one of two approaches:

- Average Range Estimation method—- Calculate an estimate of the process standard deviation based on the average of moving ranges.

- Average Standard Deviation Estimation method—- Calculate an estimate of the process standard deviation based on the average of moving standard deviations.

Sigma Calculation—Average Range Method

Using this method the process sigma is derived as follows:

$$3\,\sigma = 3\,\frac{\bar{R}}{d_2}$$
$$= E_2\,\bar{R}$$

where the constants d_2 and $E_2 = 3/d2$ are 1.128 and 2.660, respectively, for two-period moving range calculations.

The two-period average moving range is calculated as:

$$\bar{R} = \frac{\sum_{k=1}^{n-1} R_k}{n-1}$$

where 2-period moving ranges are:

$$R_k = |X_{k+1} - X_k|$$

with n, the sample size and X_k, the individual measurements.

Sigma Calculation—Average Standard Deviation Method

The sample standard deviation σ, is calculated from individual measurements as:

$$3\sigma = 3\,\frac{\bar{s}}{c_4}$$
$$= E_3\,\bar{s}$$

where the constants c_4 and $E_3 = 3/c4$ are .8862 and 3.385, respectively, for 3-period moving standard deviation calculations.

The average 3-period moving standard deviation is calculated as

$$\bar{s} = \frac{\sum_{k=1}^{n-2} s_k}{n-2}$$

where 3-period moving standard deviations are:

$$s_k = \sqrt{\frac{\sum_{i=k}^{k+2}(X_k - \bar{X}_k)^2}{2}}$$

where the average for the 3-period moving subgroup k is:

$$\bar{X}_k = \frac{\sum_{i=k}^{k+2} X_i}{3}$$

with n, the sample size and X_i, the individual measurements.

X-Bar Calculations

Sample Average

Sample averages are calculated as:

$$\bar{X}_k = \frac{\sum_{i=1}^{n} X_{(k-1)*n+i}}{n}$$, for consecutive samples k = 1 to g.

where

$X_{(k-1)*n+i}$ are individual measurements (i[th] measurement of consecutive sample k)

g is the number of samples (subgroups)

n is the sample size (size of each sample)

Center Line

The Center Line is the grand average of the sample averages:

$$\bar{\bar{X}} = \frac{\sum_{k=1}^{g} \bar{X}_k}{g}$$

Control Limits

The Upper and Lower Control Limits are calculated as:

$$UCL = \bar{\bar{X}} + 3\frac{\sigma}{\sqrt{n}}$$

$$LCL = \bar{\bar{X}} - 3\frac{\sigma}{\sqrt{n}}$$

Sigma Calculation—Average Range Method

The estimate of the process standard deviation, sigma, is calculated using the average of sample ranges:

$$3\frac{\sigma}{\sqrt{n}} = 3\frac{\bar{R}}{\sqrt{n}d_2}$$

$$= A_2\bar{R}$$

where A_2 is listed in the **Factors for Averages** (page 36) table for various sample sizes n.

Average Range

The Average Range calculated as:

$$\bar{R} = \frac{\Sigma_{k=1}^{g} R_k}{g}$$

where sample ranges are:

$$R_k = \left| \text{Max}(X_{(k-1)*n+i}) - \text{Min}(X_{(k-1)*n+i}) \right|$$

with i = 1 to n in each consecutive sample k = 1 to g.

Sigma Calculation—Average Standard Deviation Method

The estimate of the process standard deviation, sigma, is calculated using the average of standard deviation as:

$$3\frac{\sigma}{\sqrt{n}} = A_3\bar{s}$$

where A3 is listed in the *Factors for Averages* (page 36) table for various sample sizes n.

Average Standard Deviation

The Average Standard Deviation is calculated as:

$$\bar{s} = \frac{\Sigma_{k=1}^{g} S_k}{g}$$

where sample standard deviations are:

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$$s_k = \sqrt{\frac{\sum_{i=1}^{n}(X_{(k-1)*n+i} - \bar{X}_k)^2}{n-1}}$$ for each sample k=1 to g

with sample averages as calculated previously.

Moving Average Calculations

Sample Averages

Sample averages are calculated as:

$$\bar{X}_k = \frac{\sum_{i=1}^{n} X_{k+i-1}}{n}$$ for each moving sample k = 1 to g

where:

X_{k+i-1} are individual measurements (ith measurement of moving sample k)

g is the number of samples (subgroups)

n is the sample size (size of each sample)

Center Line

The Center Line is the average of sample averages:

$$\bar{\bar{X}} = \frac{\sum_{i=1}^{g} \bar{X}_k}{g}$$

Control Limits

The Upper and Lower Control Limits are calculated as shown below:

$$UCL = \bar{\bar{X}} + 3\frac{\sigma}{\sqrt{n}}$$

$$LCL = \bar{\bar{X}} - 3\frac{\sigma}{\sqrt{n}}$$

Sigma Calculation—Average Range Method

The estimate of the process standard deviation, sigma, is calculated using the average of sample ranges:

$$3\frac{\sigma}{\sqrt{n}} = 3\frac{\bar{R}}{\sqrt{n}d_2}$$
$$= A_2\bar{R}$$

where A_2 is listed in the **Factors for Averages** (page 36) table for various sample sizes n.

Average Range

The Average Range is calculated as:

$$\bar{R} = \frac{\Sigma_{k=1}^{g} R_k}{g}$$

where sample ranges are:

$R_k = \left| \text{Max}(X_{k+i-1}) - \text{Min}(X_{k+i-1}) \right|$ with i = 1 to n in each moving sample k = 1 to g.

Sigma Calculation—Average Standard Deviation Method

The estimate of the process standard deviation, sigma, is calculated using the average of standard deviations as:

$$3\frac{\sigma}{\sqrt{n}} = A_3 \bar{s}$$

where A_3 is listed in the **Factors for Averages** (page 36) table for various sample sizes n.

Average Standard Deviation

The Average Standard Deviation is calculated as:

$$\bar{s} = \frac{\Sigma_{k=1}^{g} \bar{s}_k}{g}$$

where sample standard deviations are:

$$s_k = \sqrt{\frac{\Sigma_{i=1}^{n}(X_{k-i+1} - \bar{X}_k)^2}{n-1}}$$ for each sample k=1 to g

with sample averages as calculated previously.

Exponentially Weighted Moving Average (EWMA) Calculations

Sample Averages

The averages for consecutive samples are:

$$\bar{X}_k = \frac{\Sigma_{i=1}^{n} X_{(k-1)*n+i}}{n}$$, for samples k = 1 to g.

where:

$X_{(k-1)*n+i}$ are individual measurements (i^{th} measurement of consecutive sample k)

g is the number of samples (subgroups)

n is the sample Size (size of each sample)

If the sample size is 1, sample averages $\bar{X}_k$ are individual measurements X_i.

Transformation of individual observations

The consecutive sample averages are transformed into a series of weighted averages:

$$Z_k = \lambda \bar{X}_k + (1 - \lambda)Z_{k-1} \text{ for k = 1 to g}$$

with

$$Z_1 = \bar{X}_1$$

where λ is the weighting factor.

Center Line

The Center Line is the average of the transformed data and calculated as:

$$\bar{Z} = \frac{\sum_{k=1}^{g} Z_k}{g}$$

Control Limits

The equations needed for calculating the upper and lower Control Limits are similar to as those used for the Individuals charts except that they take into account the weighting factor λ.

$$UCL = \bar{X} + 3\sqrt{\left[\frac{\lambda}{2-\lambda}\right]}\sigma$$

$$LCL = \bar{X} - 3\sqrt{\left[\frac{\lambda}{2-\lambda}\right]}\sigma$$

Sigma Calculation—Average Moving Range Method

$$UCL = \bar{Z} + L\,\bar{R}$$
$$LCL = \bar{Z} - L\,\bar{R}$$

where:

$$L = \frac{3}{d_2}\sqrt{\left[\frac{\lambda}{2-\lambda}\right]}$$

Because EWMA involves two-period calculations, $d_2 = 1.128$, $E_2 = 2.66$ and for various values of λ, L is calculated as:

λ	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
L	0.610	0.887	1.117	1.330	1.536	1.741	1.952	2.172	2.175

Average Range

The Average Range is calculated as:

$$\bar{R} = \frac{\Sigma_{k=1}^{g} R_k}{g}$$

where sample ranges are:

$R_k = \left| Max(X_{k+i-1}) - Min(X_{k+i-1}) \right|$ with i = 1 to n in each moving sample k = 1 to g.

Range Calculations

Sample Ranges

The ranges of individual samples are:

$R_k = \left| Max(X_{(k-1)*n+i}) - Min(X_{(k-1)*n+i}) \right|$ for i = 1 to n in each sample k = 1 to g.

Center Line

The Center Line is calculated from sample ranges as:

$$\bar{R} = \frac{\Sigma_{k=1}^{g} R_k}{g}$$

Control Limits

Upper Control Limit:

$$UCL = D_4\bar{R}$$

Lower Control Limit:

$$LCL = D_3\bar{R}$$

The constants D_3 and D_4 are listed in the *Factors for Ranges* (page 37) table for various sample sizes n.

Moving Range Calculations

Sample Ranges

The ranges of individual samples are:

$R_k = \left| Max(X_{k-i+1}) - Min(X_{k-i+1}) \right|$ with i = 1 to n in each moving sample k = 1 to g.

Center Line

The Center Line is calculated from sample ranges as:

$$\bar{R} = \frac{\Sigma_{k=1}^{g} R_k}{g}$$

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Control Limits

See *Range Calculations* (page 34) for upper and lower control limits.

Standard Deviation Calculations

Sample Standard Deviations

The standard deviations of individual samples are calculated as:

$$s_k = \sqrt{\frac{\sum_{i=1}^{n}(X_{(k-1)*n+i} - \bar{X}_k)^2}{n-1}}$$ in each sample k = 1 to g

where:

$X_{(k-1)*n+i}$ are individual measurements, for i = 1 to n

g is the number of samples (subgroups)

n is the sample size (size of each sample)

Sample averages, $\bar{X}_k$, are calculated as:

$$\bar{X}_k = \frac{\sum_{i=1}^{n} X_{(k-1)*n+i}}{n}$$, for consecutive samples k = 1 to g.

Center Line

The Center Line is the Average Standard Deviation which is calculated from sample standard deviations as:

$$\bar{s} = \frac{\sum_{k=1}^{g} s_k}{g}$$

Control Limits

Upper Control Limit:

$$UCL = B_4 \bar{s}$$

Lower Control Limit:

$$LCL = B_3 \bar{s}$$

B_3 and B_4 are listed in the **Factors for Standard Deviations** (page 38) table for various sample sizes n.

Moving Standard Deviation Calculations

Sample Standard Deviations

The standard deviations of individual samples are calculated as:

$$s_k = \sqrt{\frac{\sum_{i=1}^{n}(X_{k-i+1} - \bar{X}_k)^2}{n-1}}$$ for each sample k=1 to g

where:

X_{k-i+1} are individual measurement, i = 1 to n

g is the number of samples (subgroups)

n is the sample size (size of each sample)

Sample averages, $\bar{X}_k$, are calculated as:

$$\bar{X}_k = \frac{\sum_{i=1}^{n} X_{k-i+1}}{n}$$, for consecutive samples k = 1 to g.

Center Line

The Center Line is the Average Standard Deviation, which is calculated from sample standard deviations as:

$$\bar{s} = \frac{\sum_{k=1}^{g} s_k}{g}$$

Control Limits

See *Standard Deviation Calculations* (page 35) for upper and lower control limits.

Factors

The following sections detail factors used in control chart calculations. In all tables, n is the sample size.

Factors for Averages

Observations in Sample, n

n	A2	A3
2	1.880	2.659
3	1.023	1.954
4	0.729	1.628

n	A2	A3
5	0.577	1.427
6	0.483	1.287
7	0.419	1.182
8	0.373	1.099
9	0.337	1.032
10	0.308	0.975
11	0.285	0.927
12	0.266	0.886
13	0.249	0.850
14	0.235	0.817
15	0.223	0.789
16	0.212	0.763
17	0.203	0.739
18	0.194	0.718
19	0.187	0.698
20	0.180	0.680
21	0.173	0.663
22	0.167	0.647
23	0.162	0.633
24	0.157	0.619
25	0.153	0.606

Factors for Ranges

Observations in Sample n

n	d2	D1	D2	D3	D4
2	1.128	0	3.686	0	3.267
3	1.693	0	4.358	0	2.574
4	2.059	0	4.698	0	2.282
5	2.326	0	4.918	0	2.114
6	2.534	0	5.078	0	2.004
7	2.704	0.204	5.204	0.076	1.924
8	2.847	0.388	5.306	0.136	1.864
9	2.970	0.547	5.393	0.184	1.816
10	3.078	0.687	5.469	0.223	1.777

n	d2	D1	D2	D3	D4
11	3.173	0.811	5.535	0.256	1.744
12	3.258	0.922	5.594	0.283	1.717
13	3.336	1.025	5.647	0.307	1.693
14	3.407	1.118	5.696	0.328	1.672
15	3.472	1.203	5.741	0.347	1.653
16	3.532	1.282	5.782	0.363	1.637
17	3.588	1.356	5.820	0.378	1.622
18	3.640	1.424	5.856	0.391	1.608
19	3.689	1.487	5.891	0.403	1.597
20	3.735	1.549	5.921	0.415	1.585
21	3.778	1.605	5.951	0.425	1.575
22	3.819	1.659	5.979	0.434	1.566
23	3.858	1.710	6.006	0.443	1.557
24	3.895	1.759	6.031	0.451	1.548
25	3.931	1.806	6.056	0.459	1.541

Factors for Standard Deviations

Observations in Sample n

n	c4	B3	B4	B5	B6
2	0.7979	0	3.267	0	2.606
3	0.8862	0	2.568	0	2.276
4	0.9123	0	2.266	0	2.088
5	0.9400	0	2.089	0	1.964
6	0.9515	0.030	1.970	0.029	1.874
7	0.9594	0.118	1.882	0.113	1.806
8	0.9650	0.185	1.815	0.176	1.751
9	0.9693	0.239	1.761	0.232	1.707
10	0.9727	0.284	1.716	0.276	1.669
11	0.9754	0.321	1.679	0.313	1.637
12	0.9776	0.354	1.646	0.346	1.610
13	0.9794	0.382	1.618	0.374	1.585
14	0.9810	0.406	1.594	0.399	1.563
15	0.9823	0.428	1.572	0.421	1.544
16	0.9835	0.448	1.552	0.440	1.526

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n	c4	B3	B4	B5	B6
17	0.9845	0.466	1.534	0.458	1.511
18	0.9854	0.482	1.518	0.475	1.496
19	0.9862	0.497	1.503	0.490	1.483
20	0.9869	0.510	1.490	0.504	1.470
21	0.9876	0.523	1.477	0.516	1.459
22	0.9882	0.534	1.466	0.528	1.448
23	0.9887	0.545	1.455	0.539	1.438
24	0.9892	0.555	1.445	0.549	1.429
25	0.9896	0.565	1.435	0.559	1.420

Mathematical Symbols

The following mathematical symbols are used in calculations.

M = Number of Samples

n = Number of measurements in a Sample

g = Number of samples

R_i = Sample Range

$\overline{R}$ = Average Range

$\overline{R}_m$ = Average Moving Range

S_i = Sample standard deviation

$\overline{s}$ = Average sample standard deviation

Xmax = Maximum measurement within a sample

Xmin = Minimum measurement within a sample

X_i = Individual Observation

$\overline{X}_i$ = Sample Average

$\overline{X} = \sum_{i=1}^{m} X_i$ = Average of Samples

$\overline{\overline{X}} = \sum_{i=1}^{m} \overline{X}_i$ = Grand Average of Samples

λ = Weighting Factor for EWMA charts

Process Capability Index (Cpk)

The Process Capability Index (Cpk) or "process potential" refers to the ability of a process to produce products that meet customer specifications.

The larger the Cpk number, the more likely a process is capable of producing product within specifications.

Cpk is calculated as follows:

Upper and lower control limits are assumed to be different. One-sided capability indexes are determined by:

Cpu = (USL - μ)/3σ

Cpl = (μ - LSL)/3σ

where:

μ is process mean

σ is process standard deviation

Then the Cpk capability index is determined by:

Cpk = Min(Cpu, Cpl)

If, in the rare case the standard deviation is zero, the process capability index cannot be calculated and the Cpk is set to N/A.

Glossary

Fluctuating Measurements

All processes have parameters that can be measured. Repeated measurement of a process's parameters will show fluctuations in the parameter's value. Fluctuations can be classified as natural or unnatural.

Natural Pattern

A pattern of measurements of a process parameter exhibiting natural variability due to minute fluctuations in raw materials, equipment, measurement precision, etc. Obviously, natural fluctuations result in natural patterns. A natural pattern will always have the all of the following characteristics:

1. Most of the points are near the Center Line.

2. A few of the points spread out and approach the Control Limits

None (or at least only a very rare point) exceeds the Control Limits.

Process

A process is a set of conditions or causes that work together to produce a result. In an industrial setting a process can be a single control loop, a unit operation, a laboratory measurement, a task performed by a single person or a team, or virtually any combination of 'actors' which work together to produce a result.

Sample Grouping

Breaking a large collection of measurements into subgroups. Evaluating sample averages and ranges provides a more sensitive tool for spotting process variations with definable causes (unnatural patterns).

Tests for Unnatural Patterns

There are two basic premises for testing the naturalness of a pattern:

- o Test individual points versus limits
- o Test multiple points for trend - there are several commonly accepted tests for trend recognition (e.g. 8 points in a row on one side of the plot center line)

Unnatural patterns indicate possible process variations with definable causes.

Unnatural Fluctuation

These are large, abnormal fluctuations due to some external cause. The causes of unnatural fluctuations are generally definable to some outside influence. For example, an unnatural fluctuation could arise from software malfunction, field instrument failure, putting the wrong material into the product or similar causes.

Unnatural Pattern

A pattern of measurements of a process parameter exhibiting large fluctuations due to a definable cause. An unnatural pattern will lack one or more of the three characteristics of a natural pattern.

Appendix C

Technical Support and Resources

You can read complete information about technical support options, and access all of the following resources at the OSIsoft Technical Support Web site:

http://techsupport.osisoft.com (http://techsupport.osisoft.com)

Before You Call or Write for Help

When you contact OSIsoft Technical Support, please provide:

- Product name, version, and/or build numbers
- Computer platform (CPU type, operating system, and version number)
- The time that the difficulty started
- The message log(s) at that time

Help Desk and Telephone Support

You can contact OSIsoft Technical Support 24 hours a day. Use the numbers in the table below to find the most appropriate number for your area. Dialing any of these numbers will route your call into our global support queue to be answered by engineers stationed around the world.

Office Location	Access Number	Local Language Options
San Leandro, CA, USA	1 510 297 5828	English
Philadelphia, PA, USA	1 215 606 0705	English
Johnson City, TN, USA	1 423 610 3800	English
Montreal, QC, Canada	1 514 493 0663	English, French
São Paulo, Brazil	55 11 3053 5040	English, Portuguese
Altenstadt, Germany	49 6047 9890	English, German
Manama, Bahrain	973 1758 4429	English, Arabic
Singapore	65 6391 1811 86 021 2327 8686	English, Mandarin Mandarin
Perth, WA, Australia	61 8 9282 9220	English

Support may be provided in languages other than English in certain centers (listed above) based on availability of attendants. If you select a local language option, we will make best efforts to connect you with an available Technical Support Engineer (TSE) with that language skill. If no local language TSE is available to assist you, you will be routed to the first available attendant.

If all available TSEs are busy assisting other customers when you call, you will be prompted to remain on the line to wait for the next available TSE or else leave a voicemail message. If you choose to leave a message, you will not lose your place in the queue. Your voicemail will be treated as a regular phone call and will be directed to the first TSE who becomes available.

If you are calling about an ongoing case, be sure to reference your case number when you call so we can connect you to the engineer currently assigned to your case. If that engineer is not available, another engineer will attempt to assist you.

Search Support

From the OSIsoft Technical Support Web site, click **Search Support**.

Quickly and easily search the OSIsoft Technical Support Web site's Support Solutions, Documentation, and Support Bulletins using the advanced MS SharePoint search engine.

Email-based Technical Support

techsupport@osisoft.com

When contacting OSIsoft Technical Support by email, it is helpful to send the following information:

- Description of issue: Short description of issue, symptoms, informational or error messages, history of issue

- Message logs: See documentation for your PI System for information on obtaining message logs pertinent to the situation.

Online Technical Support

From the OSIsoft Technical Support Web site, click **Contact us > My Support > My Calls**.

Using OSIsoft's Online Technical Support, you can:

- Enter a new call directly into OSIsoft's database (monitored 24 hours a day)

- View or edit existing OSIsoft calls that you entered

- View any of the calls entered by your organization or site, if enabled

- See your licensed software and dates of your Service Reliance Program agreements

Remote Access

From the OSIsoft Technical Support Web site, click **Contact Us > Remote Support Options**.

OSIsoft Support Engineers may remotely access your server in order to provide hands-on troubleshooting and assistance. See the Remote Access page for details on the various methods you can use.

On-site service

From the OSIsoft Technical Support Web site, click **Contact Us > On-site Field Service Visit**.

OSIsoft provides on-site service for a fee. Visit our On-site Field Service Visit page for more information.

Knowledge Center

From the OSIsoft Technical Support Web site, click **Knowledge Center**.

The Knowledge Center provides a searchable library of documentation and technical data, as well as a special collection of resources for system managers. For these options, click Knowledge Center on the Technical Support Web site.

- The Search feature allows you to search Support Solutions, Bulletins, Support Pages, Known Issues, Enhancements, and Documentation (including user manuals, release notes, and white papers).

- System Manager Resources include tools and instructions that help you manage: Archive sizing, backup scripts, daily health checks, daylight savings time configuration, PI Server security, PI System sizing and configuration, PI trusts for Interface Nodes, and more.

Upgrades

From the OSIsoft Technical Support Web site, click **Contact Us > Obtaining Upgrades**.

You are eligible to download or order any available version of a product for which you have an active Service Reliance Program (SRP), formerly known as Tech Support Agreement (TSA). To verify or change your SRP status, contact your Sales Representative or *Technical Support* (http://techsupport.osisoft.com/) for assistance.

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