Chapter 1

IDENTIFYING DEFECTS

Pareto analysis is a simple method for separating the major causes (the ″vital few″) from the minor causes (″trivial many″) of product defects. The analysis helps in prioritizing and focusing resources where they are most needed. It can also help measure the impact of an improvement by comparing the before and after.

The Pareto principle came about when a nineteenth-century Italian economist, Vilfredo Pareto, observed that 80 percent of Italy′s wealth was owned by 20 percent of the population; therefore, the analysis is often referred to as the *80/20 rule*. In general, the rule is that 80 percent of a company s problems result from 20 percent of the causes. The split may not always be exactly 80/20, but the principle is the same: a few causes are usually responsible for a majority of the problems.

The principal objective of quality-cost analysis is cost reduction by identifying improvement opportunities, which is the goal of Pareto analysis. The analysis identifies costs by product, category, defect, or type of nonconformity. Montgomery (1997), provides an example of defects or nonconformities in the assembly of electronic components onto printed circuit boards. The study revealed that insufficient solder was the highest quality cost incurred in the operation, where insufficient solder accounted for 42 percent of the total defects in a particular board, and for almost 52 percent of the total scrap and rework costs.

Montgomery found that it was unrealistic to expect that cost of quality could be significantly reduced. However, he did believe that a quality-cost program combined with good quality-improvement efforts had the capability of reducing quality costs by 50 to 60 percent, provided that no organized effort had previously existed.

Today′s consumer dissatisfaction, due in part to the large number of failures in consumer products, has contributed most to the recent rise in the re-emergence of quality-assurance programs. Decreases in quality directly affect the corporate bottom line. These decreases, plus the increased risk of product liability, have become major social, market, and economic forces (Montgomery, 1997).

Using the Pareto Analysis

A defect or nonconformity is the unit of a product that does not satisfy one or more specifications for a product; that is, each specific point at which a unit does not meet the specification is known as a defect or nonconformity (Montgomery, 1997). This type of data is informative because there will usually be more than one type of nonconformity. By analyzing the defects by type, you often gain valuable information about the cause.

In Montgomery's printed circuit board example, there were 16 different types of defects. Plotting those defects on a Pareto Chart points out the major types of the defects (those that occur most frequently).

The Pareto Analysis in STATGRAPHICS *Plus* attempts to sort out the vital few causes to gain an understanding of where to begin an improvement process. The analysis plots the frequency of each defect type, which helps identify the most frequently occurring type of defects. The analysis does not identify the most important defects; it simply reveals the most frequent defects.

The Pareto Chart is a histogram for categorical data. This chart, together with attributes control charts, helps to identify and rank order the most important causes of a problem within a process, or to track the progress of changes to a process.

To Access the Analysis

1. Choose SPECIAL... QUALITY CONTROL... PARETO ANALYSIS... from the Menu bar to display the Pareto Analysis dialog box shown in Figure 1-1.

2. Complete the dialog box and click OK to display the Analysis Summary and the Pareto Chart in the Analysis window.

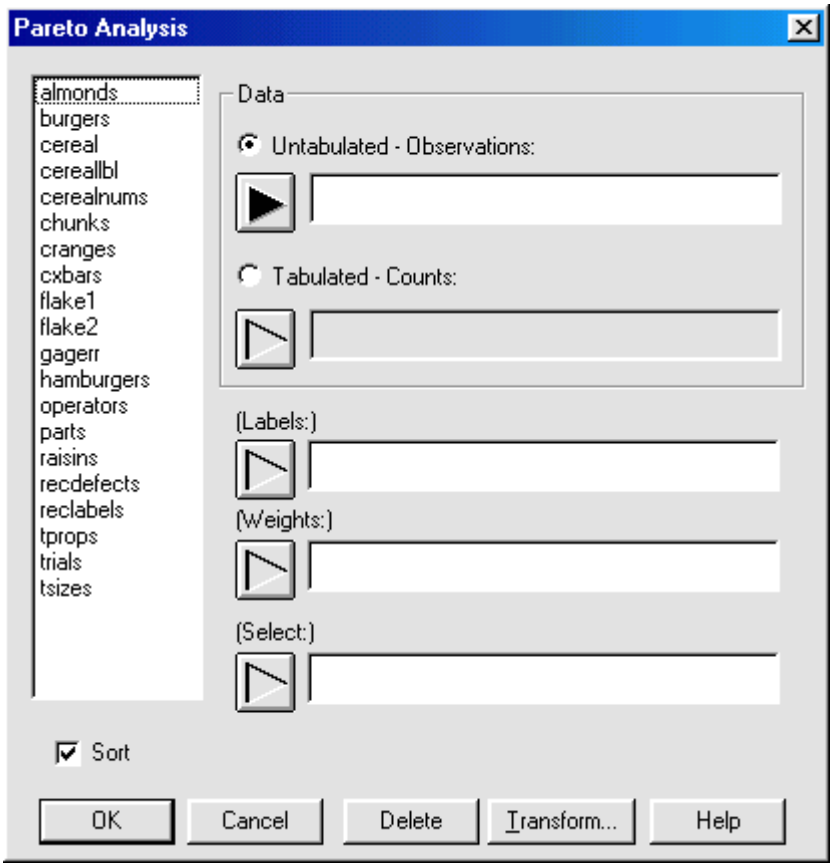


Figure 1-1. Pareto Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary that shows the name of the variable, the total count, and the number of classes in the analysis (see Figure 1-2).

Use the *Pareto Analysis Options* dialog box to indicate if small classes should be combined into a style other class, and if so, the method that will be used to combine them: Counts Less than *n*, Percentages Less than *n* , or by Smallest Classes (see Figure 1-3).

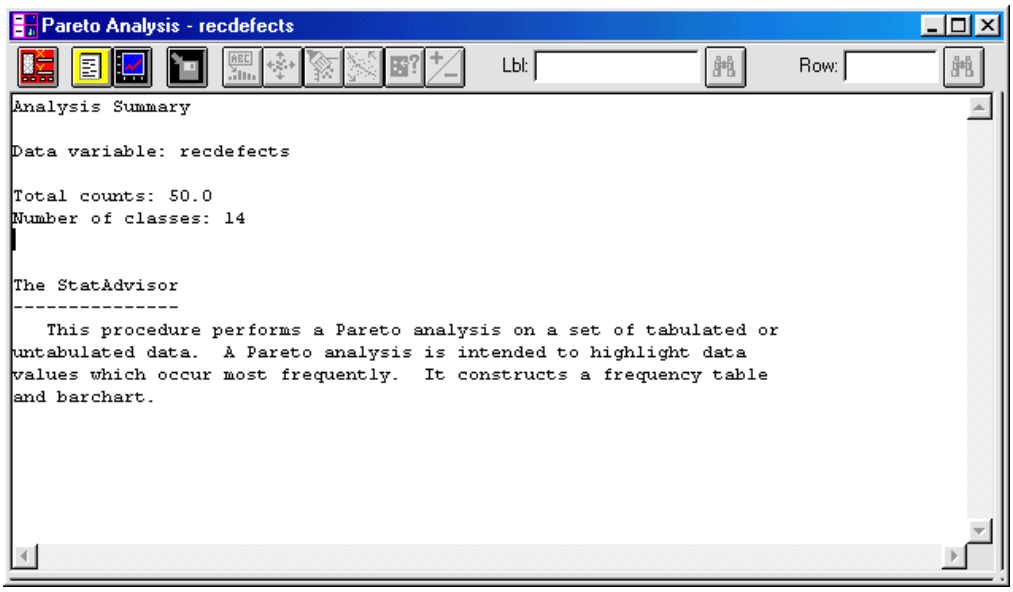


Figure 1-2. Analysis Summary

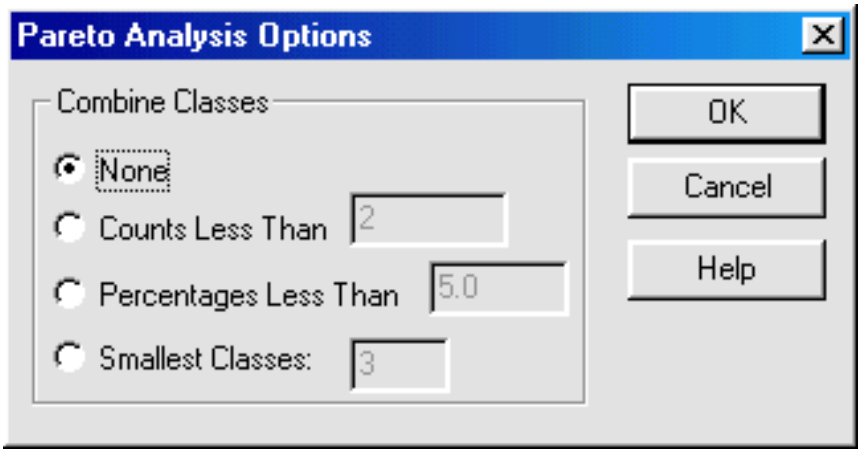
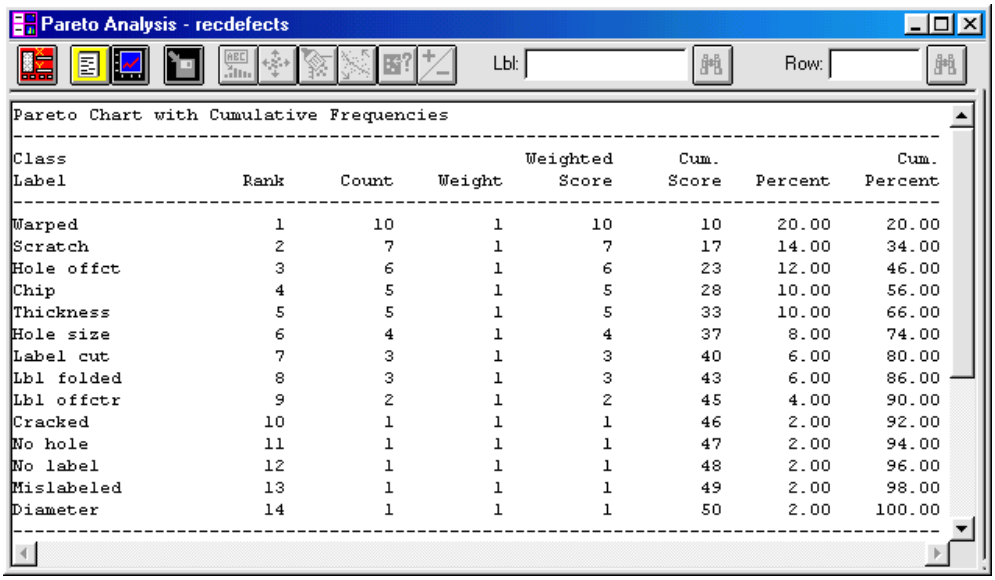


Figure 1-3. Pareto Analysis Options Dialog Box

Frequency Table

The Frequency Table option creates a table that shows either the number of occurrences of any unique values in the data (untabulated data) or the counts (see Figure 1-4). The table contains the rank, count, weight, weighted score, cumulative score, percent, and cumulative percent for each of the defect types. The program sorts the data into classes according to the weighted score, with the highest weighted score listed first. The Percentage column shows the percentage of the sum of the weighted scores represented by each class.



Pareto Chart with Cumulative Frequencies

Class Label	Rank	Count	Weight	Weighted Score	Cum. Score	Percent	Cum. Percent
Warped	1	10	1	10	10	20.00	20.00
Scratch	2	7	1	7	17	14.00	34.00
Hole offct	3	6	1	6	23	12.00	46.00
Chip	4	5	1	5	28	10.00	56.00
Thickness	5	5	1	5	33	10.00	66.00
Hole size	6	4	1	4	37	8.00	74.00
Label cut	7	3	1	3	40	6.00	80.00
Lbl folded	8	3	1	3	43	6.00	86.00
Lbl offctr	9	2	1	2	45	4.00	90.00
Cracked	10	1	1	1	46	2.00	92.00
No hole	11	1	1	1	47	2.00	94.00
No label	12	1	1	1	48	2.00	96.00
Mislabeled	13	1	1	1	49	2.00	98.00
Diameter	14	1	1	1	50	2.00	100.00

Figure 1-4. Frequency Table

Graphical Options

Pareto Chart

The Pareto Chart option creates a frequency distribution or histogram of the tabulated data arranged by category (see Figure 1-5). The total weighted score of each defect type or class is plotted against the various defect types to illustrate the defects that occur most frequently. The chart contains a bar for each category of defect; the height of the bar represents the defect frequency or weighted score. You can plot a maximum of 20 classes.

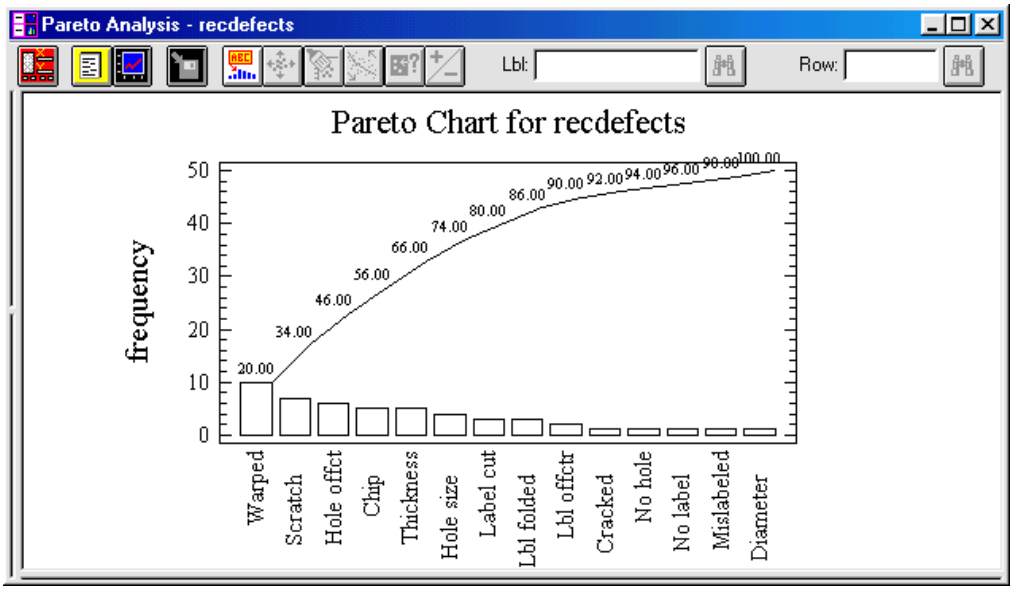


Figure 1-5. Pareto Chart

Use the *Pareto Chart Options* dialog box to indicate what the labels will display above each bar: Percentages, Scores, or None (see Figure 1-6).

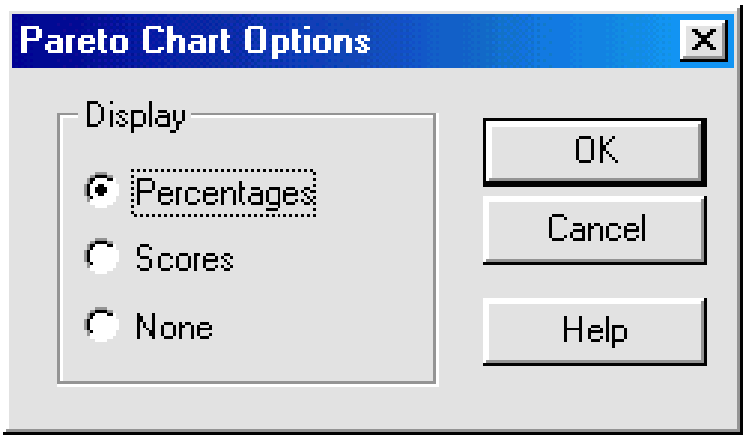


Figure 1-6. Pareto Chart Options Dialog Box

Cumulative Pareto Chart

The Cumulative Pareto Chart option produces a Pareto Chart in cumulative format (see Figure 1-7). The base of the bar for each defect-type class is plotted at the top of the previous bar; the height of the bar is equal to the weighted score for the class.

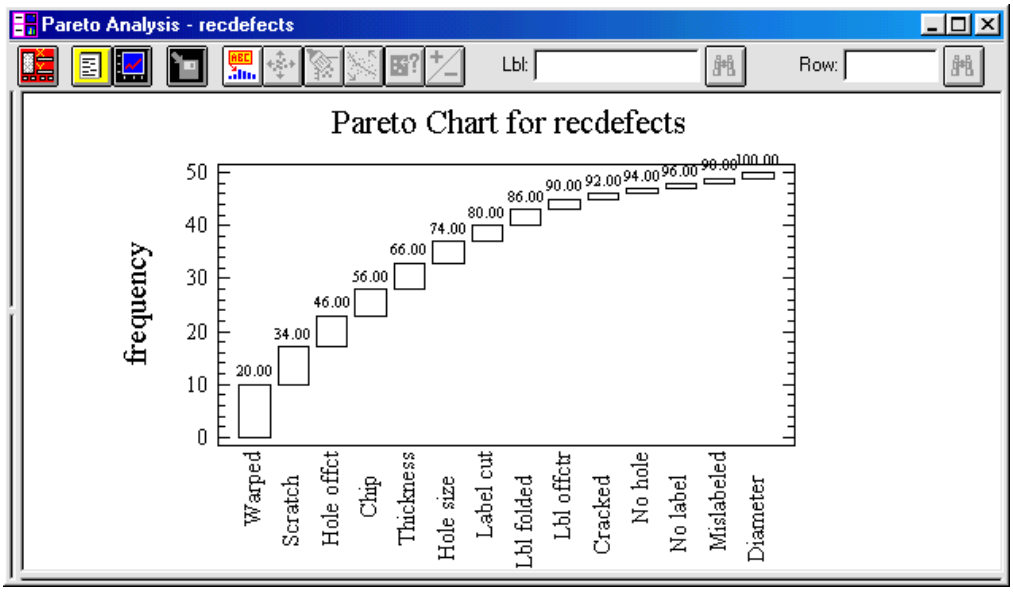


Figure 1-7. Cumulative Pareto Chart

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Montgomery, D. C. 1997. *Introduction to Statistical Quality Control*, third edition. New York: Wiley & Sons.

Chapter 2

ANALYZING THE CAPABILITY OF A PROCESS

One of the basic problems in process quality control is establishing control over a manufacturing process, then maintaining that control through time. Equally important is the problem of adjusting the process to a point where the output meets the specifications. Then two questions are relevant: Is the output meeting specifications? If not, can the process be adjusted to a level where it will?

Process capability analysis is the general activity that occurs during or prior to manufacturing when statistical techniques are utilized to analyze and quantify process variability. *Process capability* is a statistical measure of the common-cause variation exhibited by a process, and a *process capability study* is a problem-solving tool used to determine if established specifications are being met.

Variability can be divided into two types:

- variability due to common (random) causes
- variability due to assignable (special) causes.

The first type of variability occurs naturally within a process and can usually be attributed to common causes. This type of variability can never be completely eliminated from a process. Variability due to assignable causes refers to variation that can be linked to specific or special causes. If these causes or factors are modified or controlled properly, the process variability associated with them can be eliminated.

A process capability study measures the performance potential of a process when no assignable causes are present (when a process is in statistical control). Performance studies are useful for examining incoming lots of materials or one-time only production runs. In the case of incoming lots, a performance study cannot determine if the process that produced the material was in control, but it may determine the shape of the distribution and the percentage of parts that were out of specification.

Process capability studies have considerable impact on many management decision problems, including make or buy decisions, plant and process improvements that reduce process variability, and contractural agreements with customers or vendors regarding product quality (Montgomery, 1997).

Using Process Capability Studies

Process capability studies in STATGRAPHICS *Plus* estimate process capability for processes that generate data from one of eight distributions: Normal, Exponential, Extreme Value, Gamma, Laplace, Logistic, Lognormal, and Weibull. You can run the analysis with specifications that are one-sided, two-sided, or asymmetric. Normal and distribution-free tolerance limits, and nonnormal capability indices are available as options.

To Access the Process Capability Analysis

1. Choose SPECIAL... QUALITY CONTROL... PROCESS CAPABILITY ANALYSIS... from the Menu bar to display the Process Capability Analysis dialog box shown in Figure 2-1.

2. Complete the dialog box and click OK to display the Analysis Summary and the Capability Plot in the Analysis window.

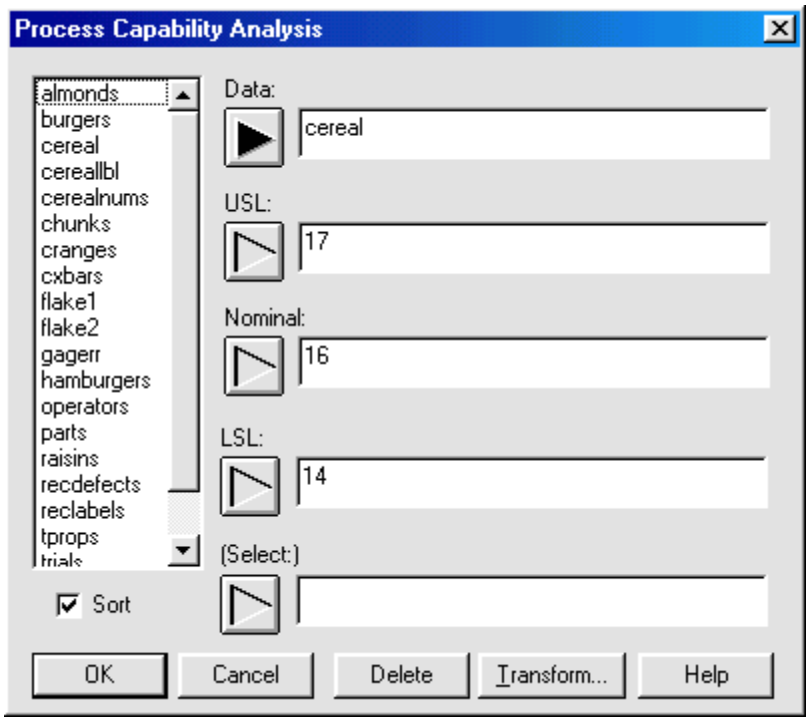

Figure 2-1. Process Capability Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option displays the results of the analysis (see Figure 2-2). The goal of the analysis is to compare a set of data with a set of specifications to

estimate the proportion of data that fall outside the specification limits. The summary includes the name of the data variable; the type of distribution; the values for the sample size; and the parameters for the fitted distribution. The table shows the percent of observations beyond the specification limits, the z-scores, and the percent of estimated observations beyond the specification limits calculated from the fitted distribution. The values for the USL, Nominal, and LSL specifications are also shown.

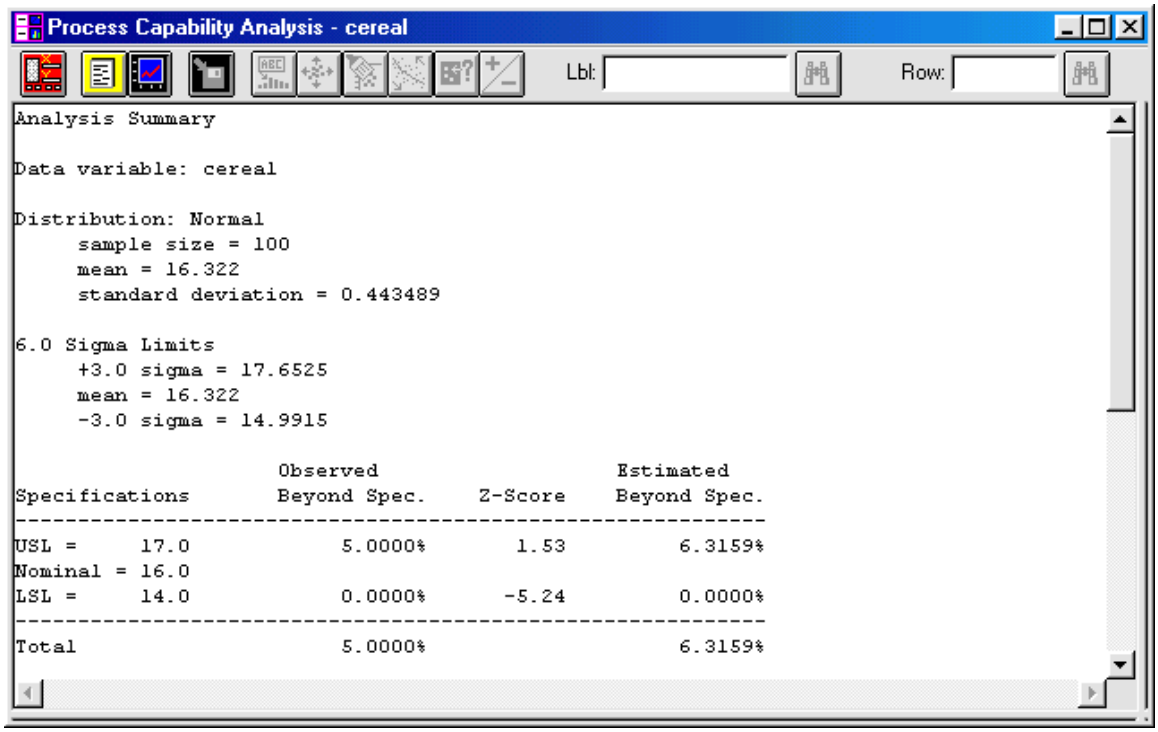

Figure 2-2. Analysis Summary

By default, a 6.0 sigma limit is used to calculate the indices, which means that the sigma spread for the process is from -3.0 standard deviations (sigmas) to +3.0 standard deviations from the estimated process mean. While you can use other sigma limits, 6.0 sigma limits is used most often because more than 99 percent of the measurements from a normally distributed process fall within the 6.0 sigma bounds.

For a normal distribution, the z-score indicates the number of standard deviations each limit is away from the sample mean. For other distributions, the z-scores are computed from the corresponding percentiles of the selected distribution. Capable processes have USL and LSL z-scores greater than +3 and less than 3, respectively.

The Observed Beyond Specifications and Estimated Beyond Specifications columns represent the total percentage of the area under the fitted normal curve that fall above and below the specification limits for the distribution. If you select another distribution, the program calculates the tail areas for that distribution.

Use the *Process Capability Analysis Options* dialog box to choose another distribution, to enter values for the two parameters of the distribution, and to enter a value for the sigma limits that will be used in the calculations (see Figure 2-3).

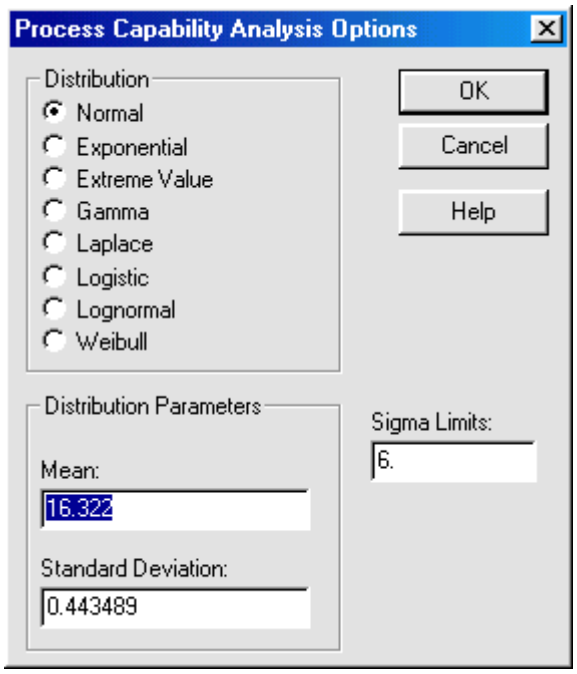

Figure 2-3. Process Capability Analysis Options Dialog Box

Capability Indices

The Capability Indices option computes capability indices for the variable you select to summarize the comparison between the data and the specifications (see Figure 2-4). The program uses either 6-sigma limits or sigma limits you select to calculate the indices. In the example shown here, 6 sigma limits were used. The report also displays confidence intervals for C_p and C_{pk}. *See the StatAdvisor for information about each type of distribution.*

Use the *Capability Indices Options* dialog box to choose the indices you want computed, and to indicate if you want to use 6 sigma limits or user-specified limits in the calculations. You can also enter a value for the confidence level and indicate how the indices will be labeled (see Figure 2-5).

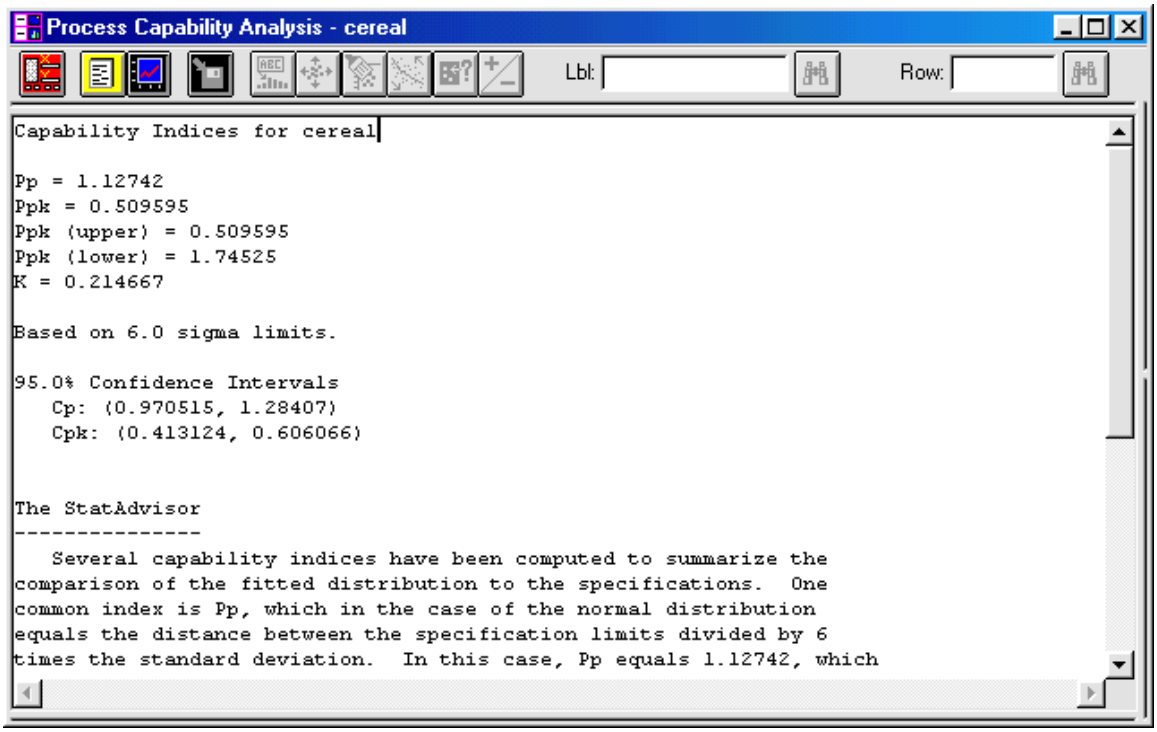

Figure 2-4. Capability Indices

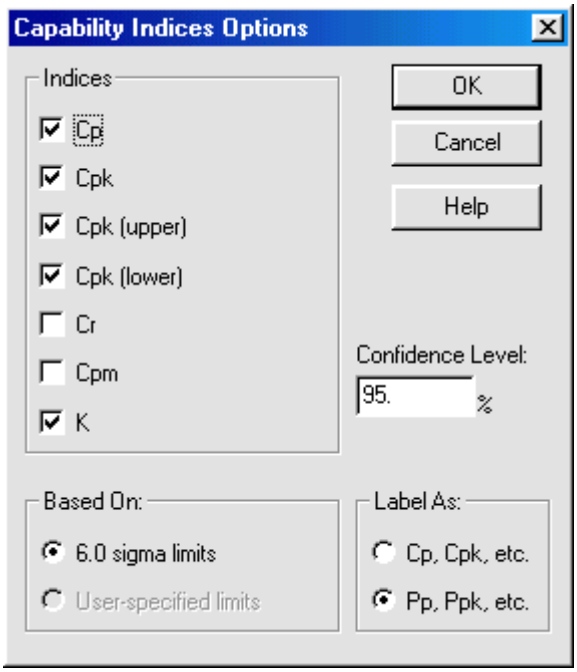

Figure 2-5. Capability Indices Options Dialog Box

Tests for Normality

The Tests for Normality option displays the results of several tests that determine if the data in the variable is adequately modeled by the normal distribution (see Figure 2-6). The tests are the Chi-Square goodness of fit, Shapiro-Wilks W, z-score for skewness, and z-score for kurtosis.

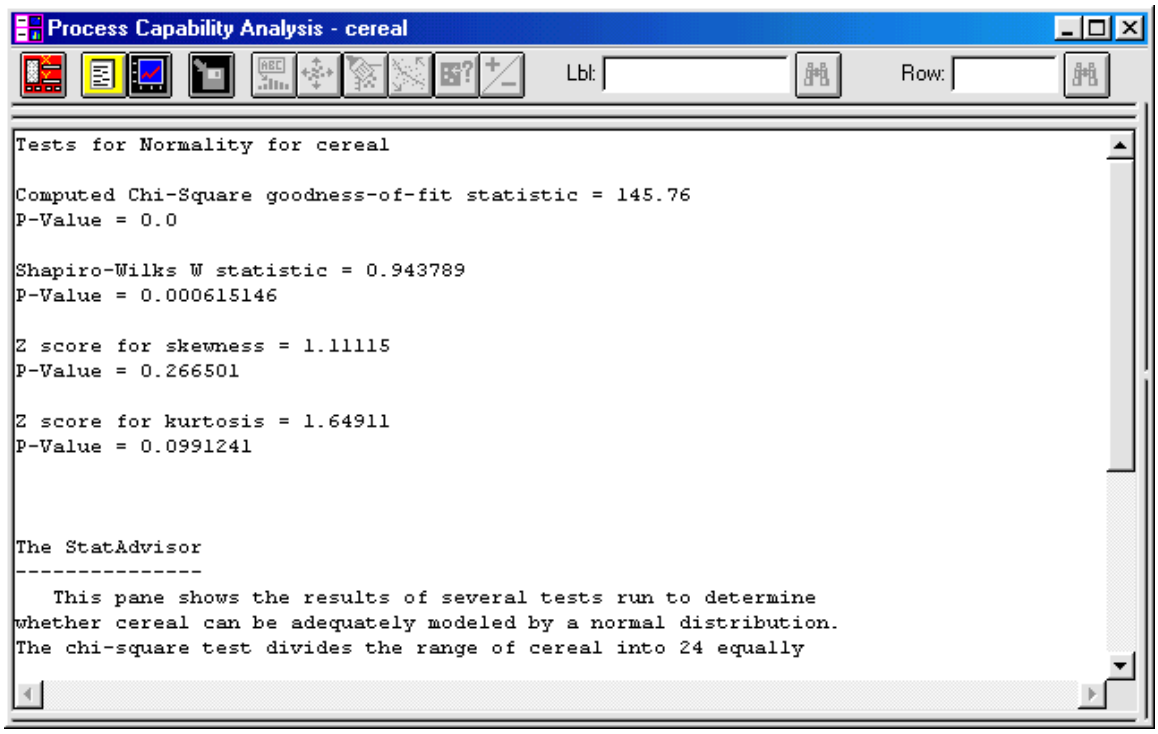

Figure 2-6. Tests for Normality

The Chi-Square test divides the range of values in the variable into equally probable classes, then compares the number of observations in each class with the number of expected observations. This is an updated version of the standard chi-square goodness-of-fit statistic (see Madansky, 1988).

The Shapiro-Wilks W test compares the quantiles of the fitted normal distribution with the quantiles of the data (see Madansky, 1988).

The Standardized Skewness Test looks for a lack of symmetry in the data. The z-score for skewness looks for symmetry in the data, while the z-score for kurtosis looks for a distribution shape that is either flatter or more peaked than the normal distribution.

Goodness-of-Fit Tests

The Goodness-of-Fit Tests option displays a table of the results for tests run to determine if the variable can be adequately modeled by the distribution you are

using, which can be either normal or nonnormal distributions (see Figure 2-7). The tests are: Chi-Square and Kolmogorov-Smirnov.

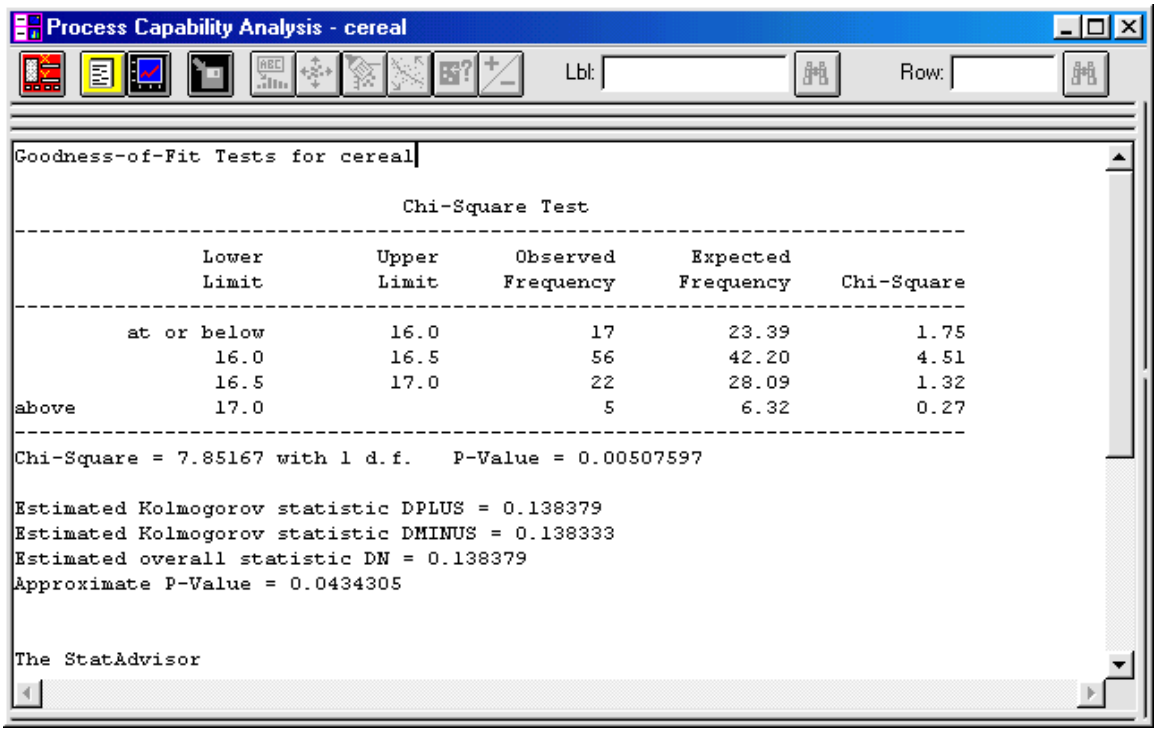

Figure 2-7. Goodness-of-Fit Tests

The Chi-Square test divides the range of values in the variable into nonoverlapping intervals and compares the number of observations in each class with the number of expected observations, based on the distribution you are using. If the *p* value is less than .05 (for a 95 percent confidence level), the data are not adequately modeled by the distribution.

The Kolmogorov-Smirnov test computes the maximum distance between the cumulative distribution of the data variable and the CDF of the distribution you are using. If the approximate *p* value falls below .05, the data do not adequately fit the distribution you are using.

Normal Tolerance Limits

The Normal Tolerance Limits option displays the values for the sample size; sample mean; and sample standard deviation; the USL, Nominal, and LSL limits for the specifications; and the resulting values for the tolerance interval (see Figure 2-8).

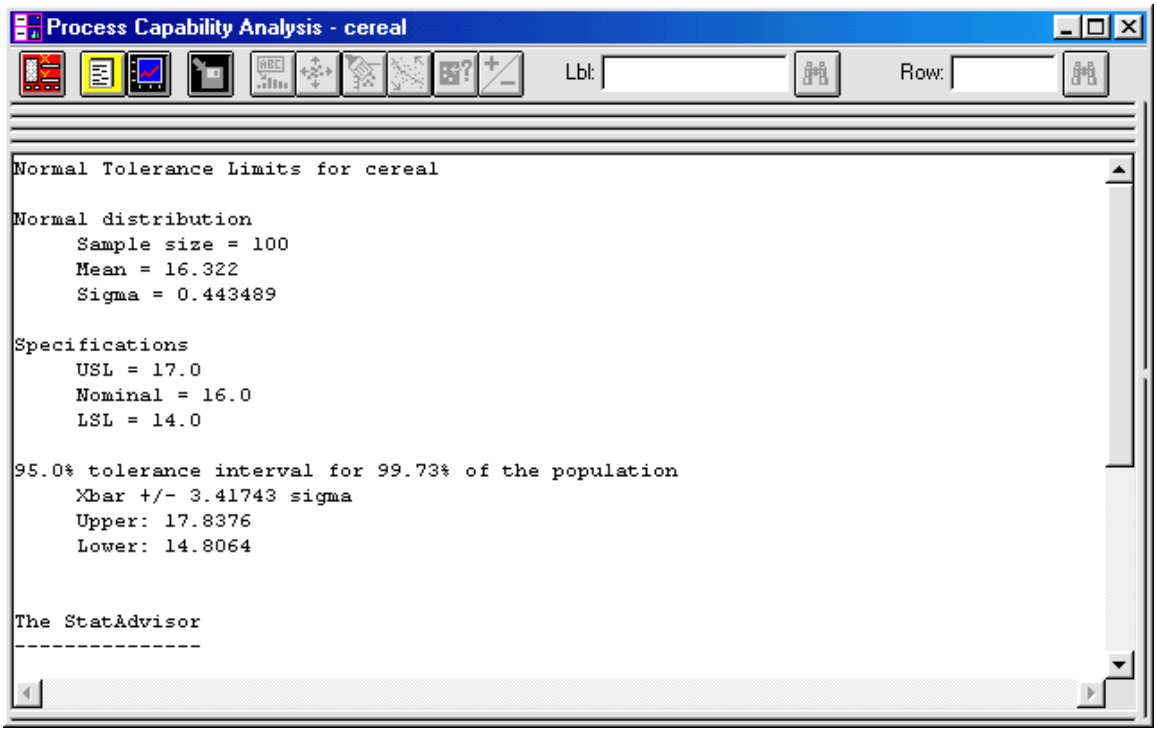

Figure 2-8. Normal Tolerance Limits

The interval is calculated by taking the mean of the data, times a multiple of the standard deviation. The results are helpful in selecting reasonable specifications for the process if they are currently not being met. The interval is reliable only if the data come from a normal distribution.

Use the *Normal Tolerance Limits Options* dialog box to enter values for the sample size, confidence level, and population proportion you want the tolerance interval to cover (see Figure 2-9).

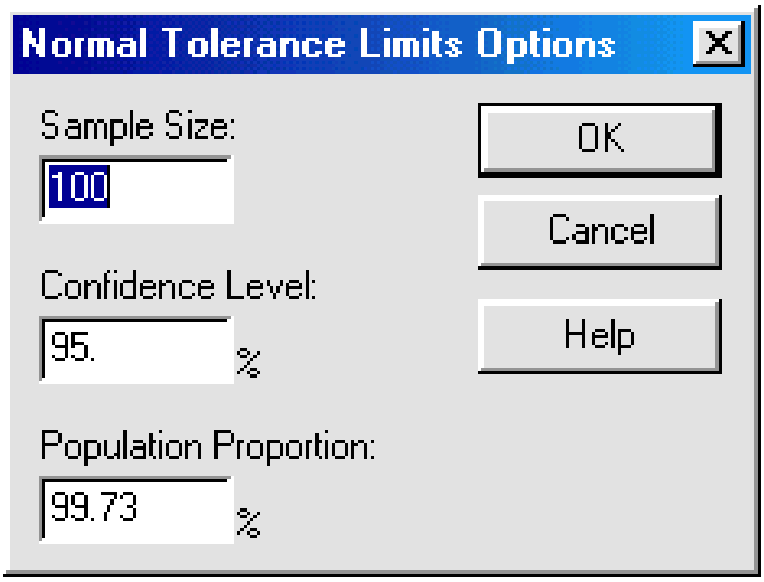

Figure 2-9. Normal Tolerance Limits Options Dialog Box

Non-Normal Capability Indices

The Non-Normal Capability Indices option produces estimates of the usual capability indices without assuming that the data come from a normal distribution (see Figure 2-10). The program first computes the sample skewness, then the kurtosis of the variable. Then, based on the estimated skewness and kurtosis, it selects a distribution from the general class of Pearson curves, and calculates estimated percentiles from the fitted curve. It uses these percentiles instead of the mean plus or minus 3.0 to calculate the capability indices.

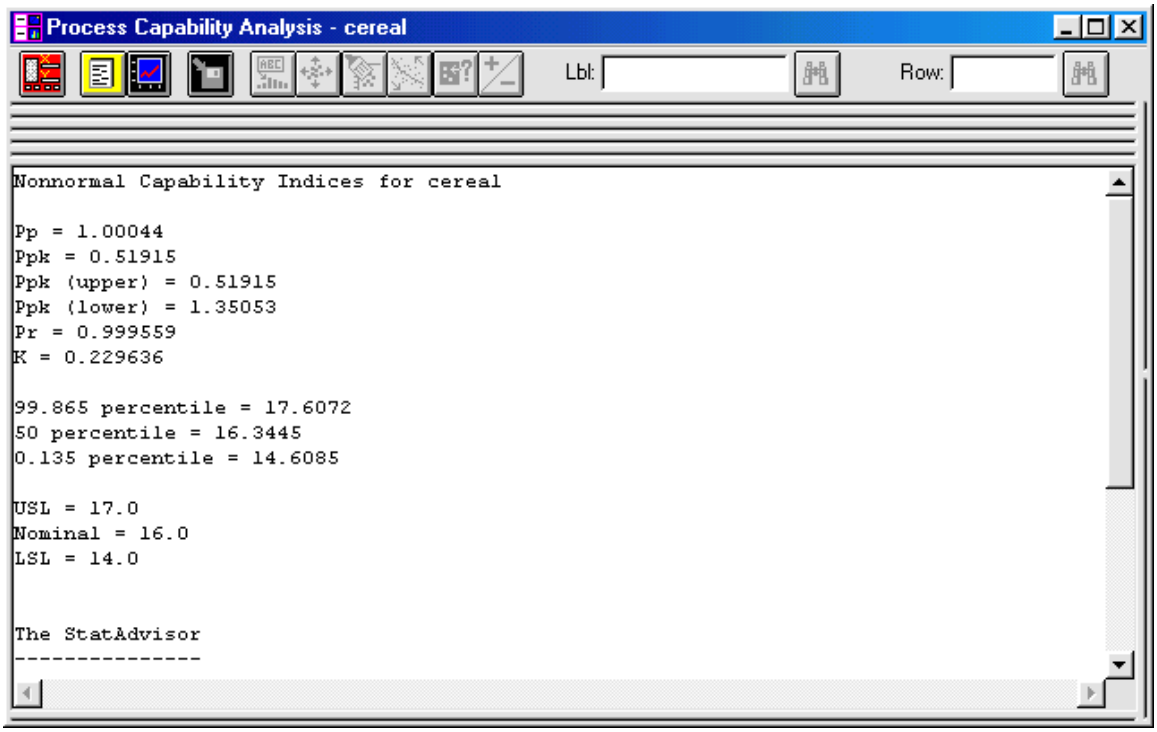

Figure 2-10. Non-Normal Capability Indices

Distribution-Free Limits

The Distribution-Free Limits option calculates tolerance limits without assuming that the variable comes from a normal distribution (see Figure 2-11). The interval is calculated using the smallest and largest values in the data, or the second smallest, or the third smallest, and so on.

Use the *Distribution-Free Tolerance Limits Options* dialog box to enter values for the confidence level, or the population proportion and interval depth (see Figure 2-12).

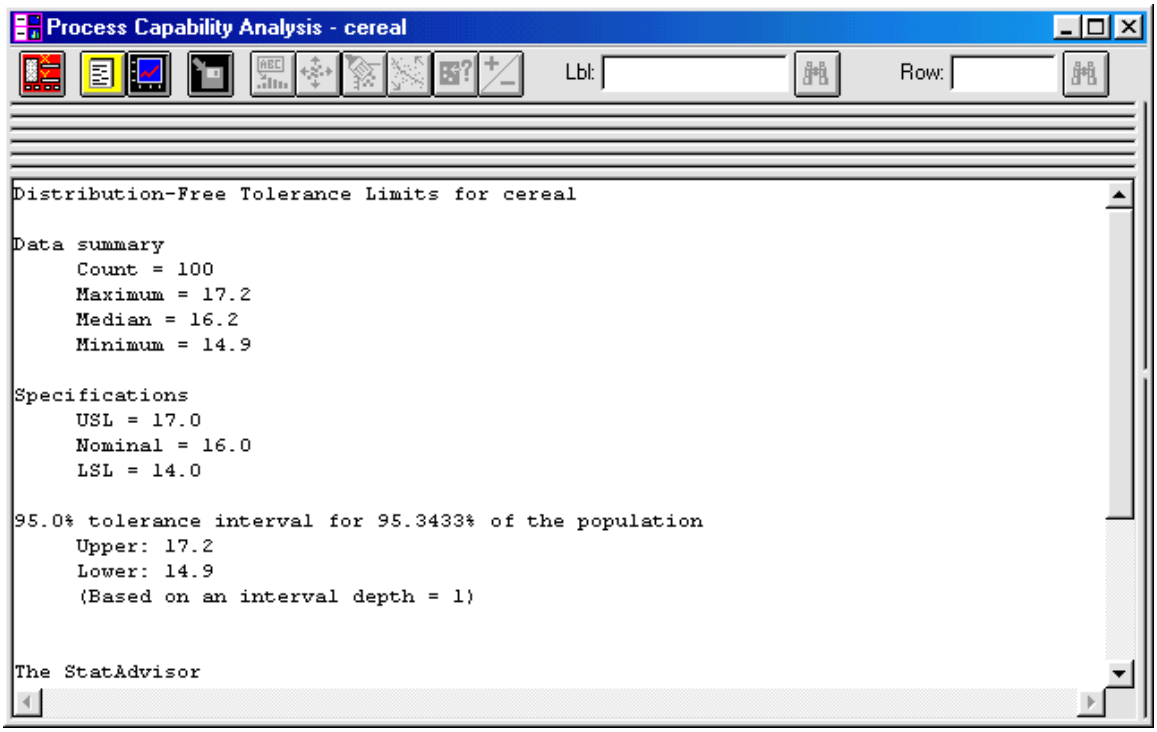

Figure 2-11. Distribution-Free Limits

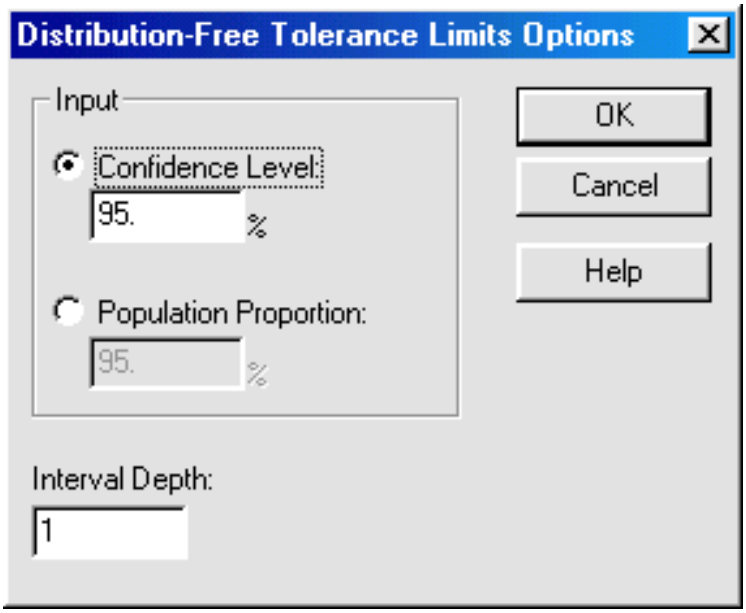

Figure 2-12. Distribution-Free Tolerance Limits Options Dialog Box

Graphical Options

Capability Plot

The Capability Plot option displays a histogram of the variable and a fitted curve of the distribution you are using (see Figure 2-13). The three taller vertical lines identify the nominal value and the specification limits. The two shorter vertical lines show the sample mean plus and minus 3.0 standard deviations for a normal distribution or equivalent percentiles for a nonnormal distribution. Because the shorter lines are not inside the taller lines, the process would be incapable of meeting the specifications.

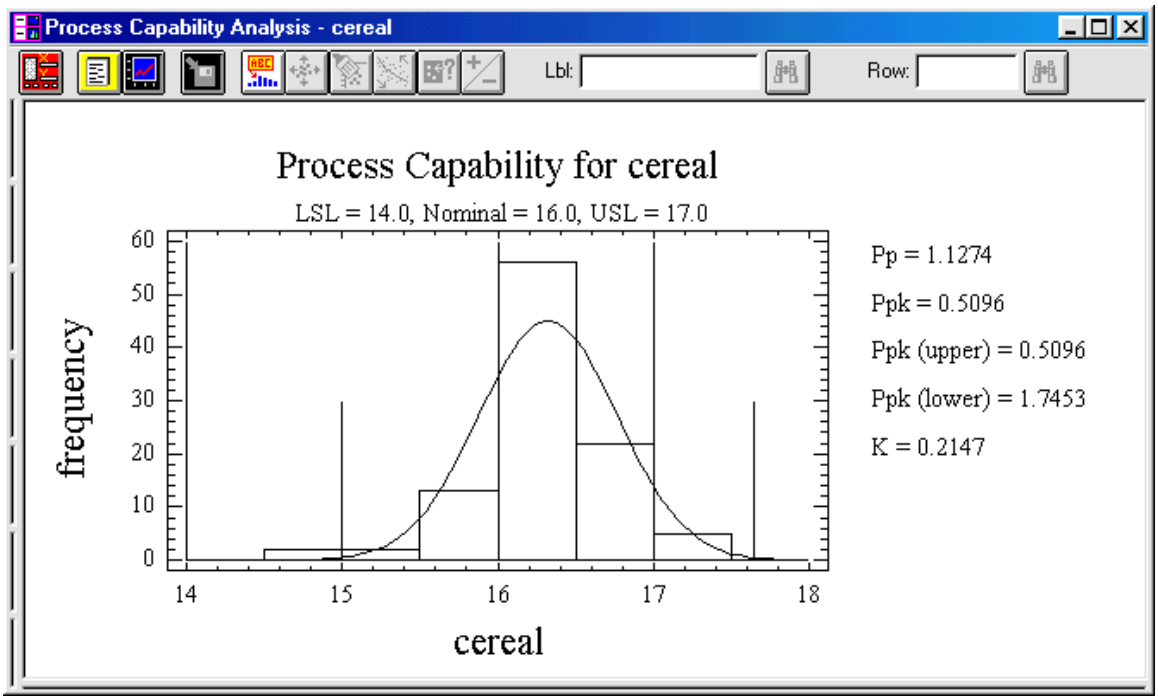

Figure 2-13. Capability Plot

Use the *Capability Plot Options* dialog box to enter values for the number of classes, lower and upper limits, and to indicate if the current scaling should be retained even if the values are changed on the Analysis dialog box. You also indicate if you want to display the indices on the plot, and enter values for the X-axis resolution and the number of decimal places for displaying the indices (see Figure 2-14).

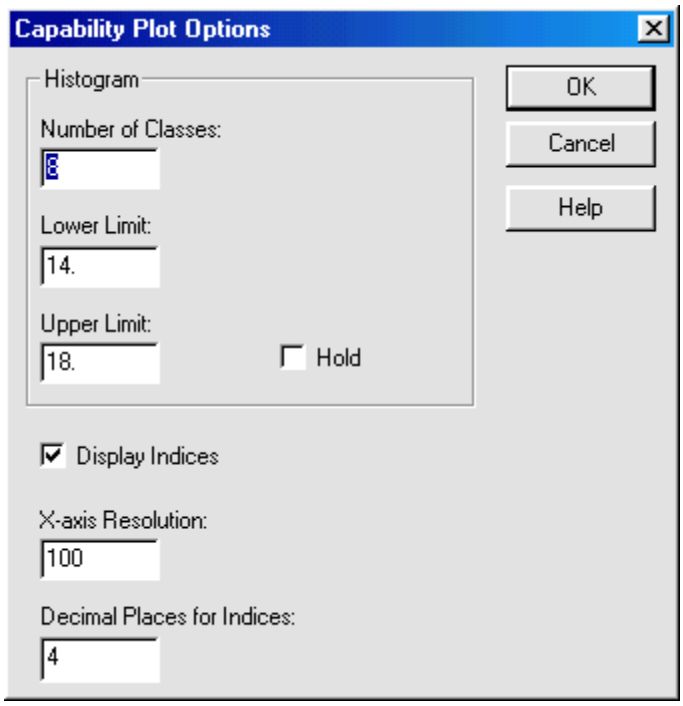

Figure 2-14. Capability Plot Options Dialog Box

Probability Plot

The Probability Plot option displays a quantile-quantile plot (see Figure 2-15). To create the plot, the program sorts the values from smallest to largest, then plots the sorted values against the equivalent quantiles of the fitted distribution. The points should fall approximately along a straight line. A reference line superimposed on the plot helps determine the closeness of the points to the line. If the points show significant curvature, it may indicate that you need to choose a different distribution.

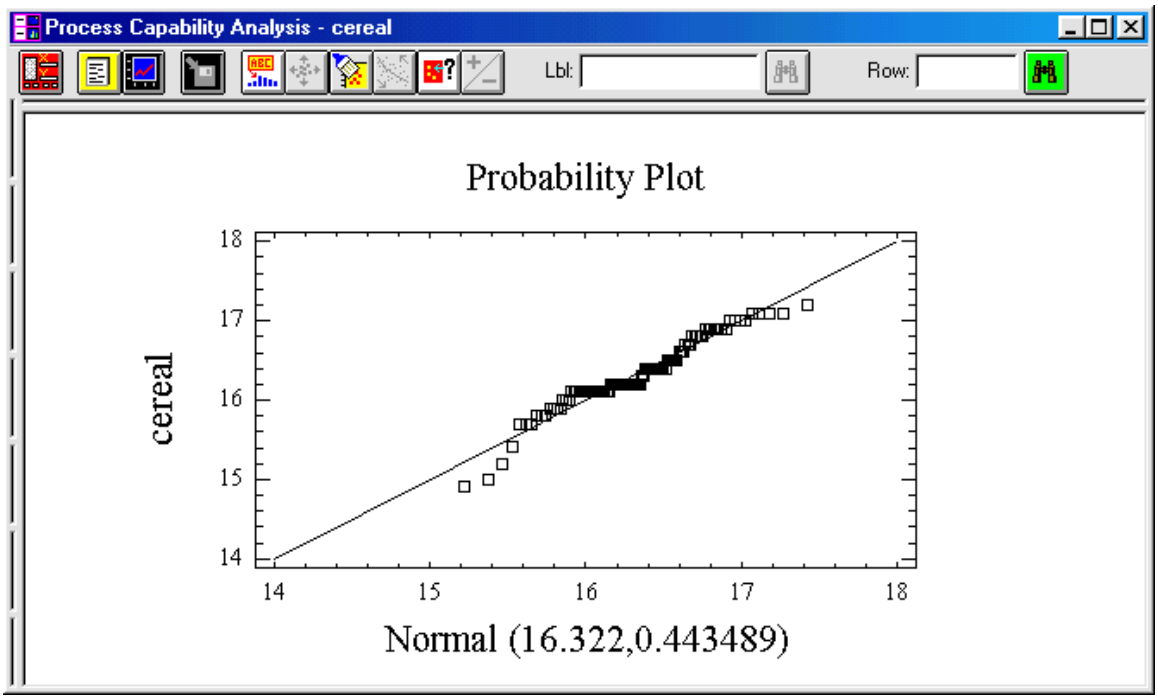

Figure 2-15. Probability Plot

Use the *Probability Plot Options* dialog box to indicate if the plot will display horizontally or vertically and if the fitted line should display on the plot (see Figure 2-16).

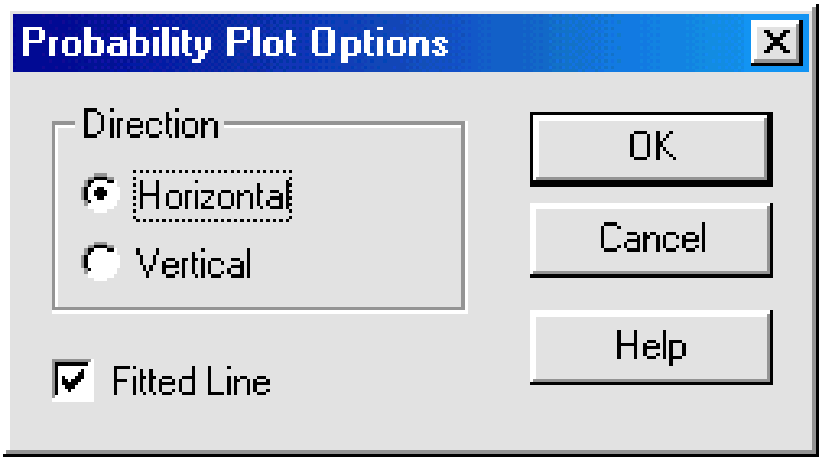

Figure 2-16. Probability Plot Options Dialog Box

References

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Chapter 3

DETERMINING STATISTICAL CONTROL OF VARIABLE DATA

An important tool in statistical quality control is the Shewhart control chart. The Shewhart technique is powerful in that it has the ability to separate out assignable causes of quality variation. This makes it possible to diagnosis and correct many production problems while bringing about substantial improvements in product quality. Because control charts tell when to leave a process alone, they prevent unnecessary process adjustments that tend to increase process variability rather than to decrease it (Grant and Leavenworth, 1980).

Control charts are an indispensable tool because they provide information that needs to be known before an action plan is set in place. The information they provide consists of knowledge about the:

- basic variability of the quality characteristic
- consistency of performance
- average level of the quality characteristic.

In the production environment, some variability is unavoidable because no process is good enough to produce every product exactly alike. The amount of variability depends on various characteristics of the production process, such as machines, materials, and operators. Once a control chart shows that a process has been brought under control at a satisfactory level and with acceptable limits of variability, process capability analyses can be performed to determine whether the the product meets specifications.

All manufactured products must meet certain requirements and many of these requirements are stated as variables. Montgomery (1997) defines variables as quality characteristics that are measured on a numerical scale. Examples include dimensions such as length or width, temperature, and volume. Most specifications for variables include both upper and lower limits for the measured value. For many requirements, however, it is necessary to state the characteristics in terms of attributes rather than variables. This applies to things that can be judged only by visual examination, such as a glass cover on a pressure gage that is either cracked or not cracked. Generally, the item being examined either conforms or does not conform to the specifications (Grant and Leavenworth, 1980).

This chapter deals exclusively with Shewhart control charts where it is ″usually necessary to monitor both the mean value of the quality characteristic and its variability. . . . Control of the process average or mean quality level is usually with the control chart for means, or the X-bar Chart. Process variability can be monitored with either a control chart for the standard deviation (the S Chart), or a control chart for the range (the Range Chart)″ (Montgomery, 1997). *Chapter 4,*

Determining Statistical Control of Attribute Data, deals with quality characteristics that are either conforming or nonconforming attributes control charts.

Using Variables Control Charts

Because variables charts can explain process data in terms of both its spread (piece-to-piece variability) and its location (process average), they are always prepared and analyzed in pairs — one for location and another for spread. STATGRAPHICS *Plus* contains the following variables control charts: X-bar and R, X-bar and S, X-bar and S-Squared, and Individuals charts (X and MR(2). If the data are observations arranged in subgroups, use one of the first three analyses; if the data contain individual items, use the Individuals charts. Each of the analyses is summarized next.

X-bar and R Charts Analysis
Produces two charts, X-bar and Range, that are constructed by estimating two parameters: mean and standard deviation. The X-bar Chart plots the averages of the sampled subgroup means; the Range Chart plots the variation via the sampled subgroup ranges; that is, the general variability.

X-bar and S Charts Analysis
Produces two charts, X-bar and S, when there is an ordered set of standard deviations on which to base the control limits, or when there are large subgroup sizes (eight or greater).

X-bar and S-Squared Charts Analysis
Produces two charts, X-bar and S-Squared, with control limits based on variances, which is useful when subgroup sample sizes are large (eight or greater).

Individuals Chart Analysis
Produces a chart that is used for individual items that are difficult to form into subgroups. For example, if:

- the manufacturing process is very slow and it is inconvenient to accumulate subgroup samples before the process is analyzed

- every unit that is manufactured must be analyzed

- measurements repeated in a process differ because of laboratory or analysis error

- measurements on some parameter in the processing environment differ very little and produce a standard deviation that is much too small.

Under any of these circumstances, it is best to use this analysis to analyze the individual items (subgroup size = 1). Chapter 5, Using Time Weighted Charts, contains information about analyses that are also appropriate to use when you

are analyzing individual items: the EWMA (Exponentially Weighted Moving Average) and CuSum charts.

In each of these analyses, you can include warning limits or moving averages, and exclude subgroups without altering the data when you run an Initial Study. When a Control to Standard study is run, you can specify a mean and standard deviation or the control limits for a process.

Using the X-bar and R Charts Analysis

The X-bar and R charts are the most commonly used pairs of variables charts. X-bar is the average of the values in small subgroups — a measure of location, while R is the range of values within each subgroup (highest minus lowest) — a measure of spread.

To Access the X-bar and R Charts Analysis

1. Choose SPECIAL... QUALITY CONTROL... VARIABLES CONTROL CHARTS... X-BAR AND R... from the Menu bar to display the X-bar and R Charts Analysis dialog box shown in Figure 3-1.

2. Complete the dialog box and click OK to display the Analysis Summary and the X-bar and R Chart in the Analysis window.

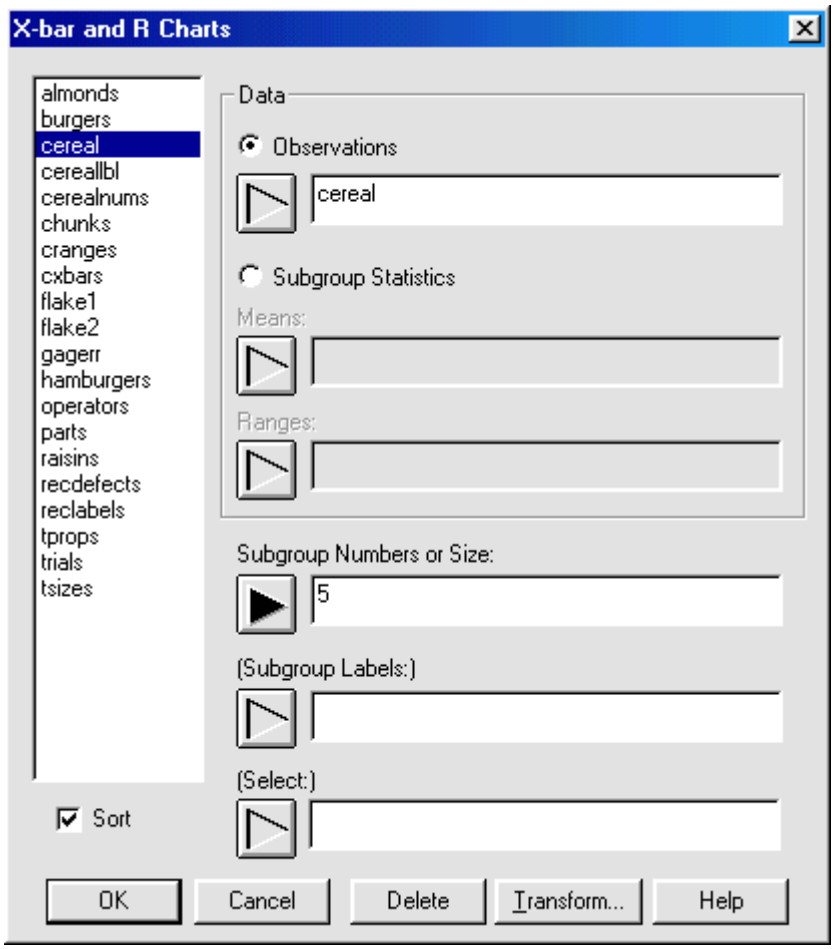

Figure 3-1. X-Bar and R Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option displays a summary of the analysis (see Figure 3-2). The analysis is designed to determine if the data are from a process that is in statistical control. The control charts are produced with the assumption that the data are from a normal distribution with the mean and standard deviation parameters.

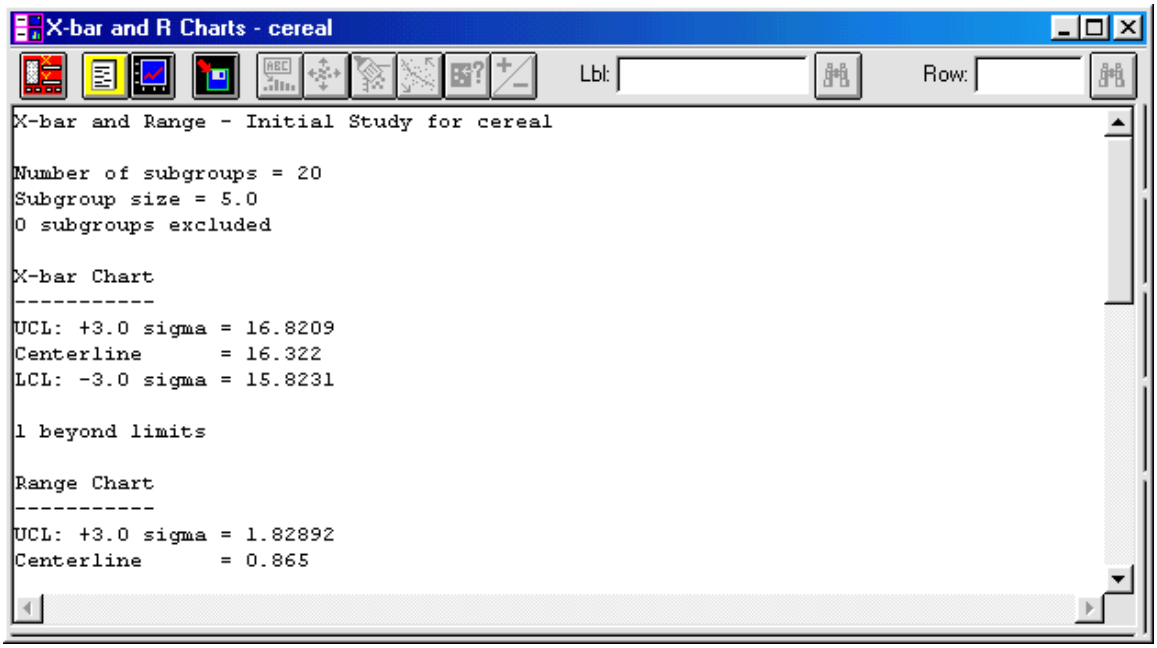

Figure 3-2. Analysis Summary

The summary also shows the type of study (Initial or Control to Standard), the variable name, the number of subgroups, the subgroup size, and the number of subgroups excluded from the study.

Values for the UCL, Centerline, and LCL and the number of subgroups beyond the limits are shown along with the estimates for the process mean and sigma, and mean range.

Use the *X-bar and R Charts Options* dialog box to indicate if you want to perform an Initial study or a Control to Standard; to indicate if the subgroup data should be normalized to z-scores; and to indicate if the average subgroup size should be used to calculate the control limits (see Figure 3-3). You can also recalculate control limits for specified sets of subgroups. You can enter values for the Upper and Lower Sigma for the X-bar Control Limits and the Range Control Limits.

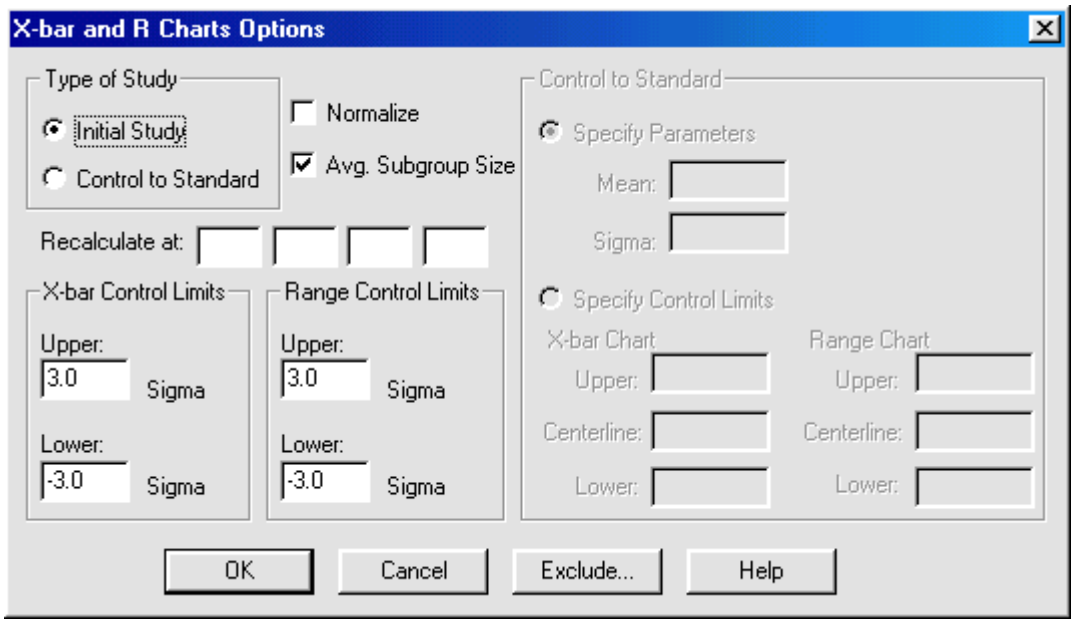

Figure 3-3. X-Bar and R Charts Options Dialog Box

For a Control-to-Standard study, you can choose to either specify parameters (mean and sigma) or to specify control limits for the two charts: X-bar Chart and Range Chart. For each of these you can enter values for the Upper, Centerline, and Lower limits.

Use the Exclude... command on the dialog box to choose the subgroups you want to exclude from the analysis. When you click the button, the Exclude/Include Options dialog box displays (see Figure 3-4).

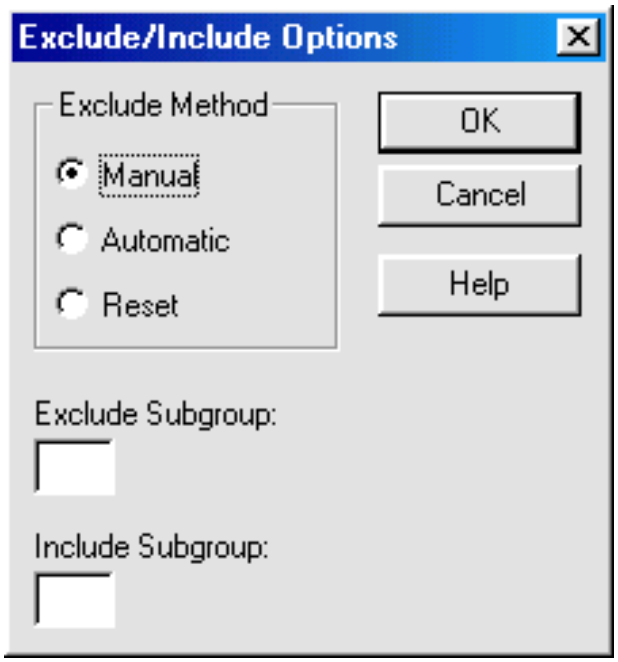

Figure 3-4. Exclude/Include Options Dialog Box

Subgroup Reports

The Subgroup Reports option creates a table that displays the values that will be plotted on the control chart (see Figure 3-5). Points that are beyond the limits are noted with an asterisk; points that are excluded are noted by an X.

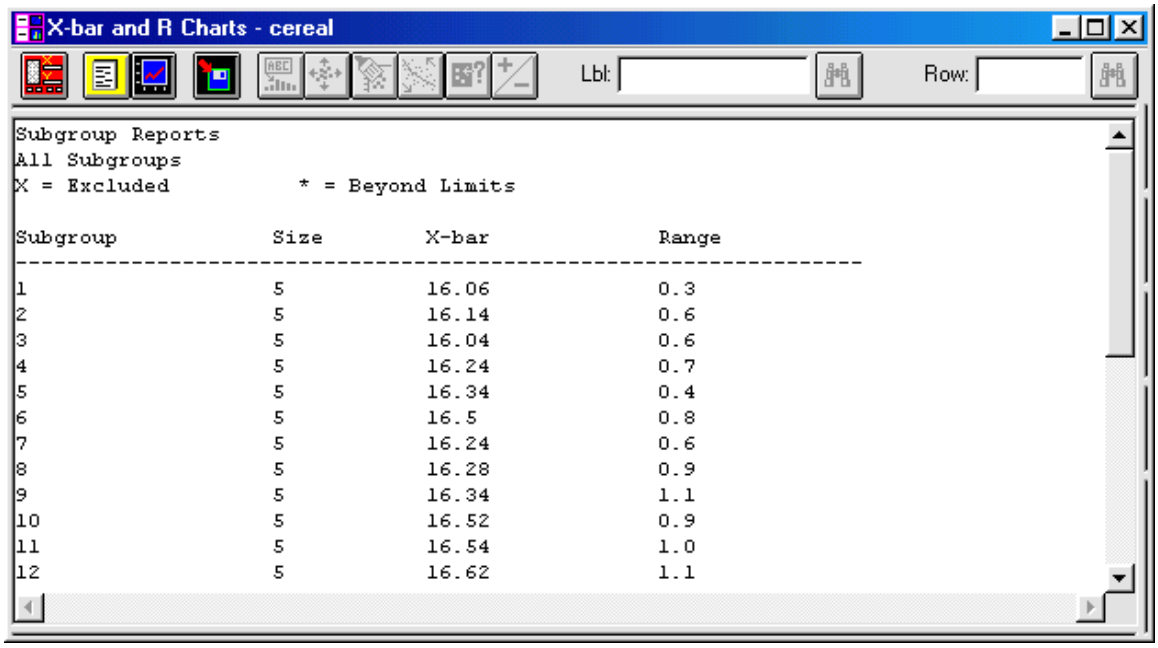

Figure 3-5. Subgroup Reports

Use the *Subgroup Reports Options* dialog box to choose the type of reports that will be included: All Subgroups, Subgroups Beyond Limits, X-bars Beyond Limits, Ranges Beyond Limits, or Excluded Subgroups (see Figure 3-6).

Figure 3-6. Subgroup Reports Options Dialog Box

Runs Tests

The Runs Tests option searches for and identifies any unusual patterns in the data (see Figure 3-7). The tests are helpful in detecting processes that are slowly drifting away from the target (even though no points may fall outside the control limits). A nonrandom pattern indicates that a process is out of control. The report displays the subgroup at which the unusual pattern was detected as well as the rule that was violated.

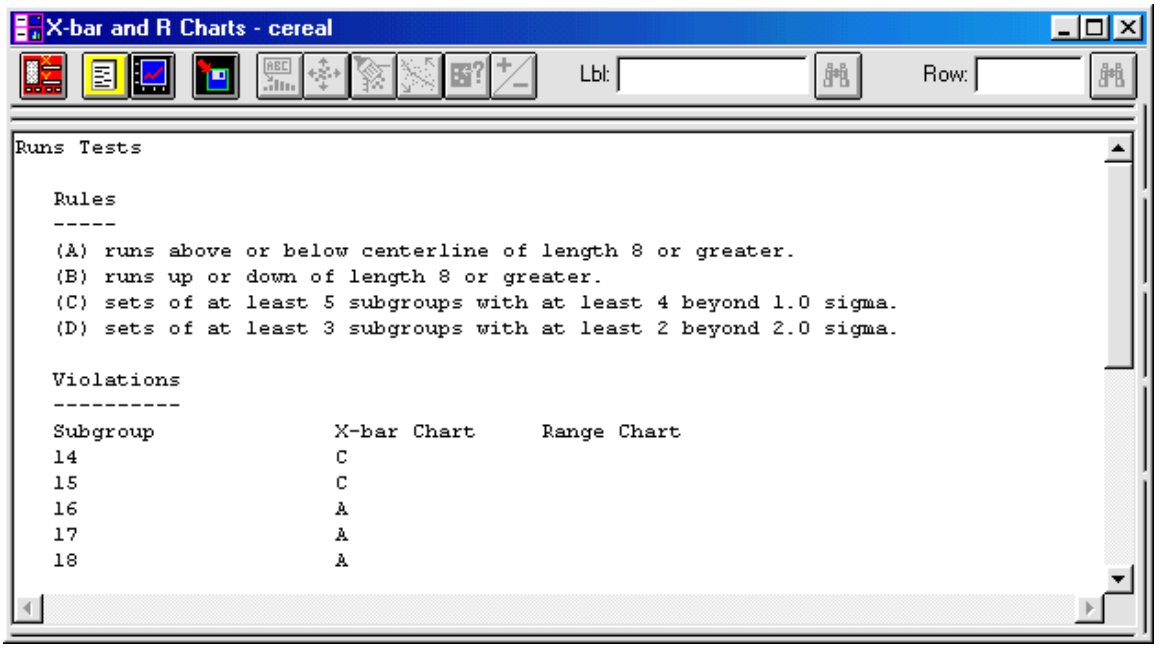

Figure 3-7. Runs Tests

Use the *Runs Tests Options* dialog box to indicate the guidelines for the tests and the violation rules (see Figure 3-8).

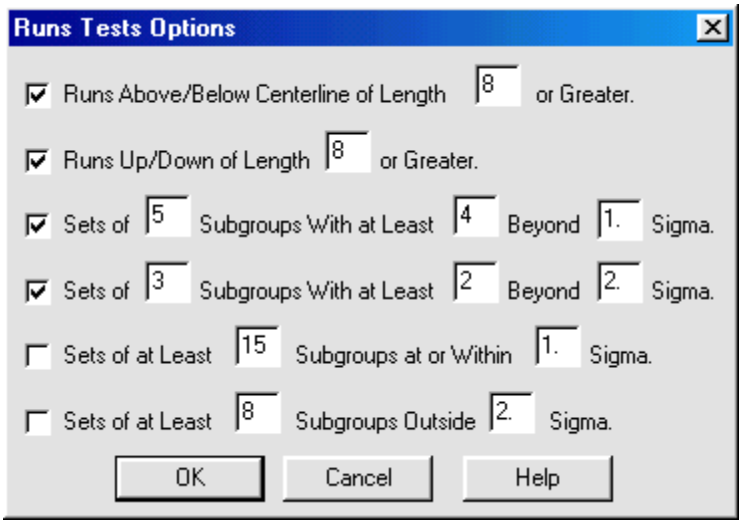

Figure 3-8. Runs Tests Options Dialog Box

Capability Indices

The Capability Indices option calculates the capability indices you choose that are based on the estimated process mean and standard deviation (see Figure 3-9). Sigma limits of 6.0 are used to calculate the indices. The values help to determine the capability of a process to produce products that meet a standard.

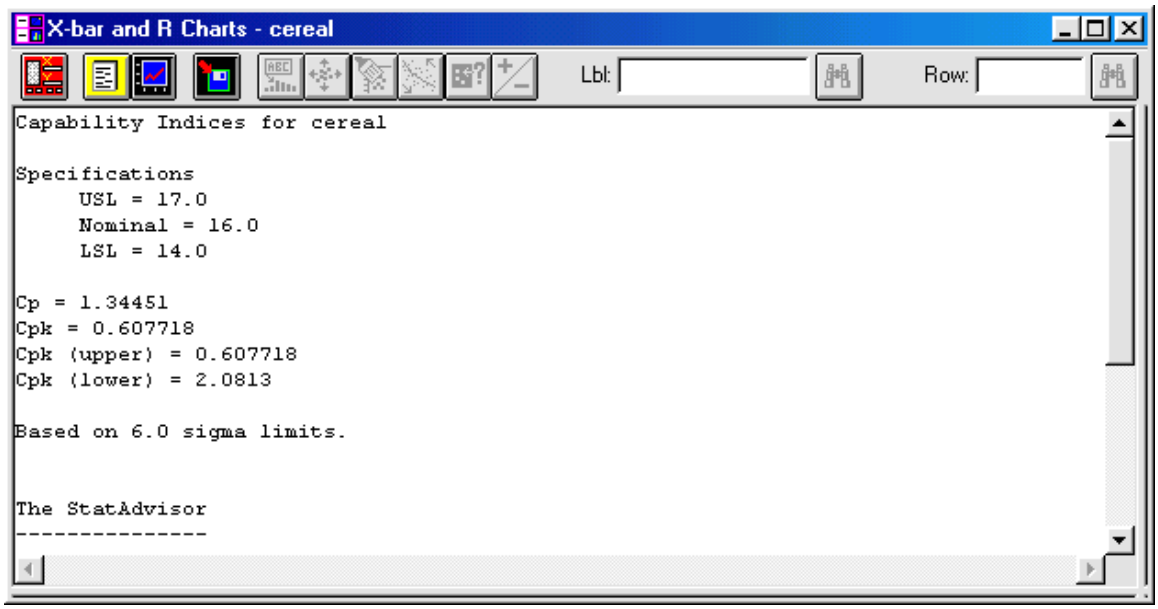

Figure 3-9. Capability Indices

Use the *Process Capability Indices Options* dialog box to choose the indices you want calculated, and to enter values for the USL, Nominal, and LSL specifications (see Figure 3-10).

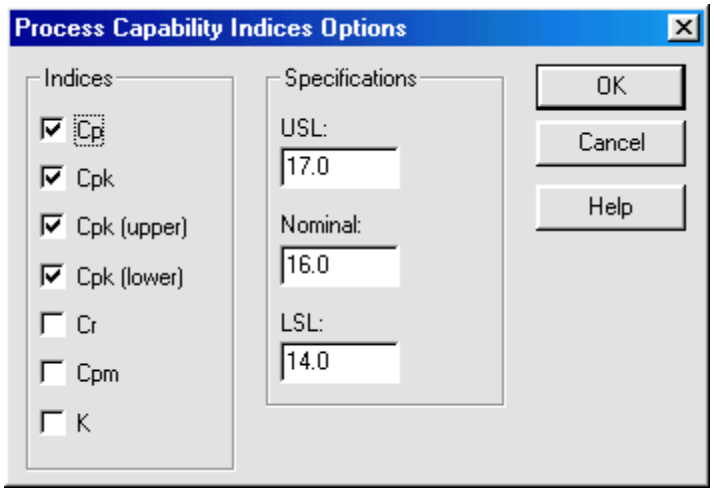

Figure 3-10. Process Capability Indices Options Dialog Box

Graphical Options

X-bar Chart

The X-bar Chart option creates a plot of the means for each of the subgroups (see Figure 3-11). A process is considered out of control if points are shown outside the

control limits, or if points are shown within the control limits, but arranged in a nonrandom sequence.

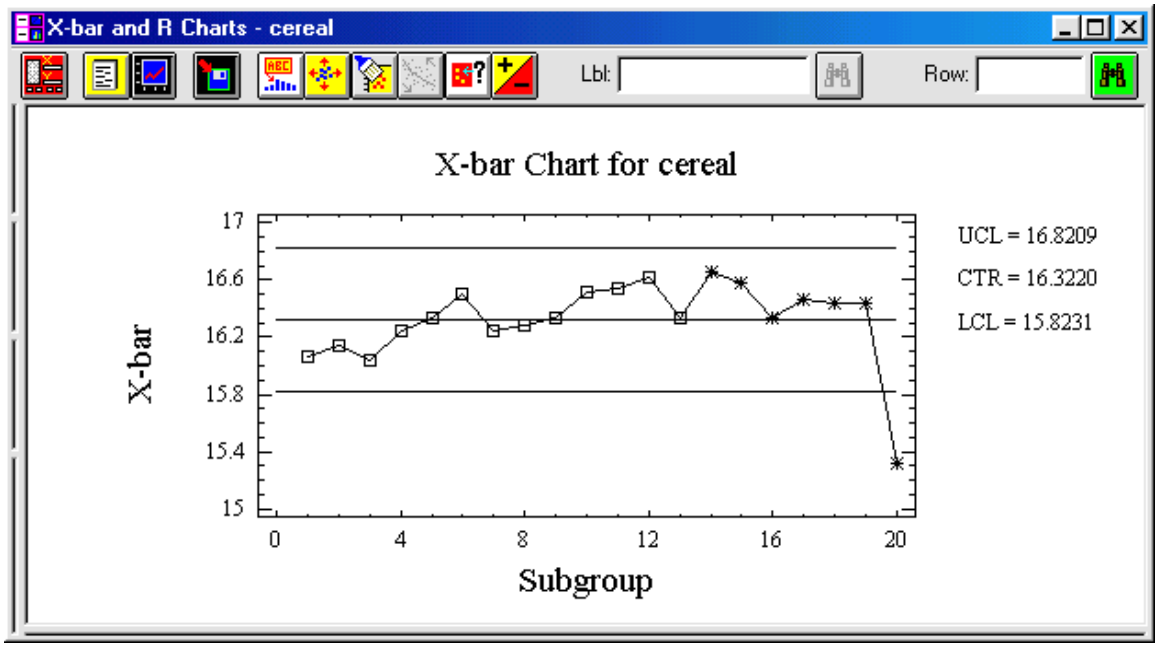

Figure 3-11. X-bar Chart

Use the *Control Chart Options* dialog box to indicate if outer and inner warning limits should be calculated, and if so, enter values for sigma (see Figure 3-12). You also indicate if the moving average and exponentially weighted moving average should be calculated, and if so, enter values for the order and lambda, respectively. You also enter a value for the number of decimal places to be used for displaying the limits, and indicate if you want the rule violations noted.

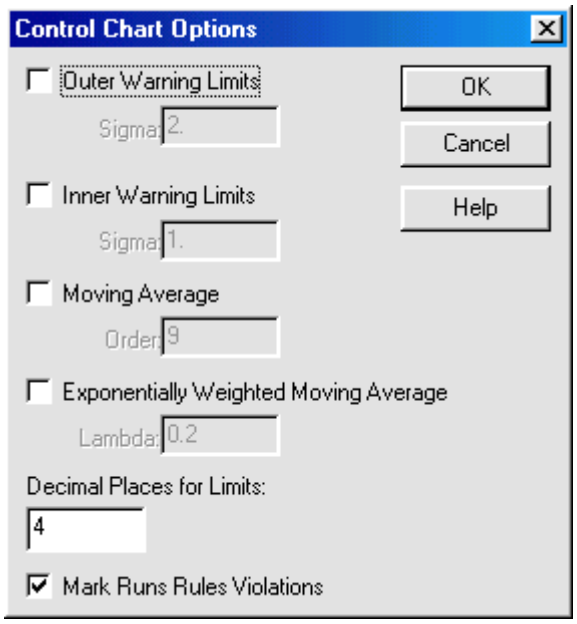

Figure 3-12. Control Chart Options Dialog Box

Range Chart

The Range Chart option creates a plot that shows the ranges for each of the subgroups (see Figure 3-13). It indicates if any points are beyond the control limits. A process is out of control if points are shown outside the control limits, or if points are within the control limits, but arranged in a nonrandom sequence.

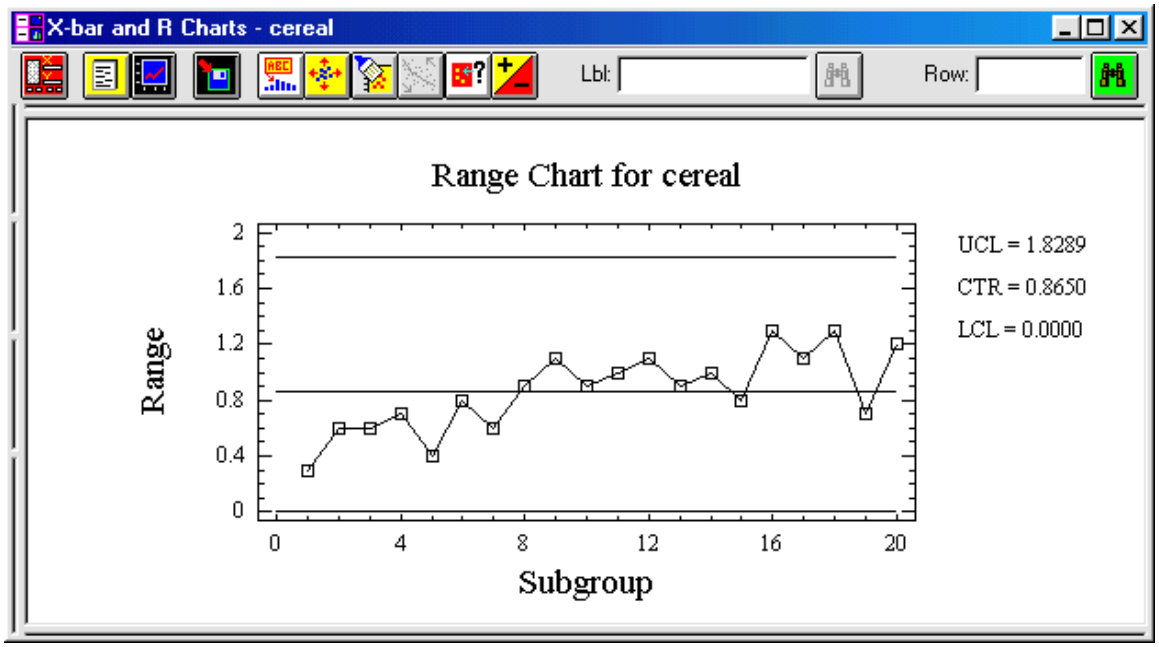

Figure 3-13. Range Chart

Use the *Control Chart Options* dialog box to indicate if outer and inner warning limits should be calculated, and if so, enter values for sigma. You also indicate if the moving average and exponentially weighted moving average should be calculated, and if so, enter values for the order and lambda, respectively. You also enter a value for the number of decimal places to be used for displaying the limits, and indicate if you want the rule violations noted. See Figure 3-12 for an example of this dialog box.

Tolerance Chart

The Tolerance Chart option creates a plot of the individual values for the variable, arranged by subgroup (see Figure 3-14). A horizontal line shows the grand mean of the observations, while a vertical line shows the subgroup ranges. You can include specification limits on the chart.

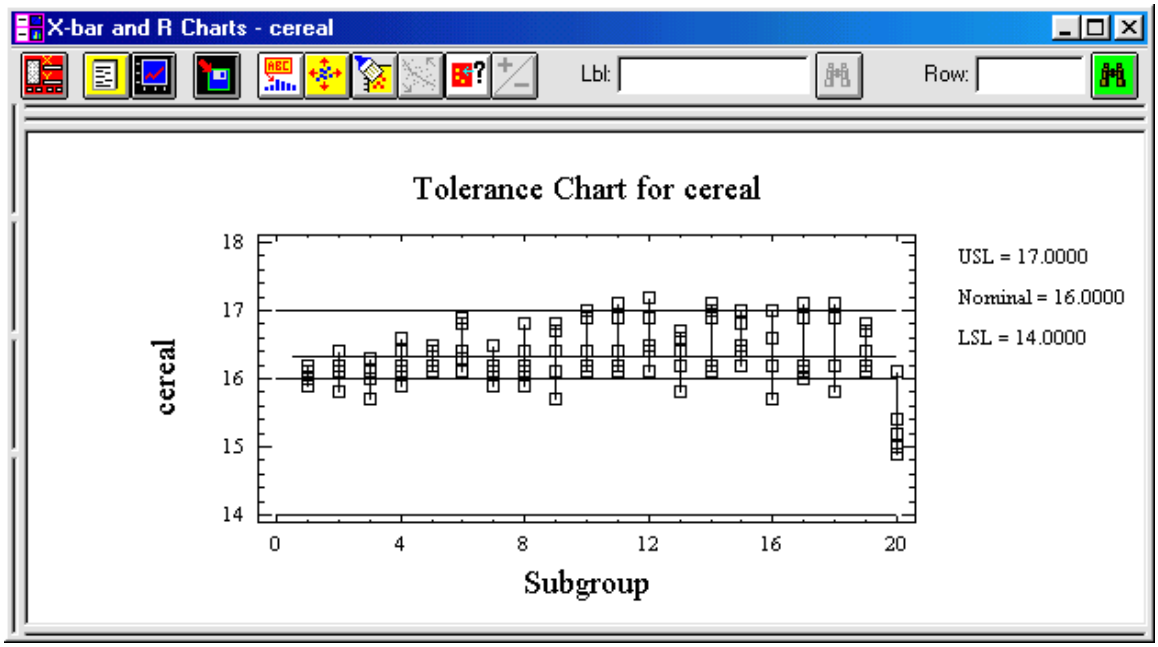

Figure 3-14. Tolerance Chart

Use the *Tolerance Chart Options* dialog box to enter values for the Upper, Nominal, and Lower specifications, to enter the number of decimal places that should be used for displaying the limits, and to indicate if points or the nominal specification line will display on the plot (see Figure 3-15).

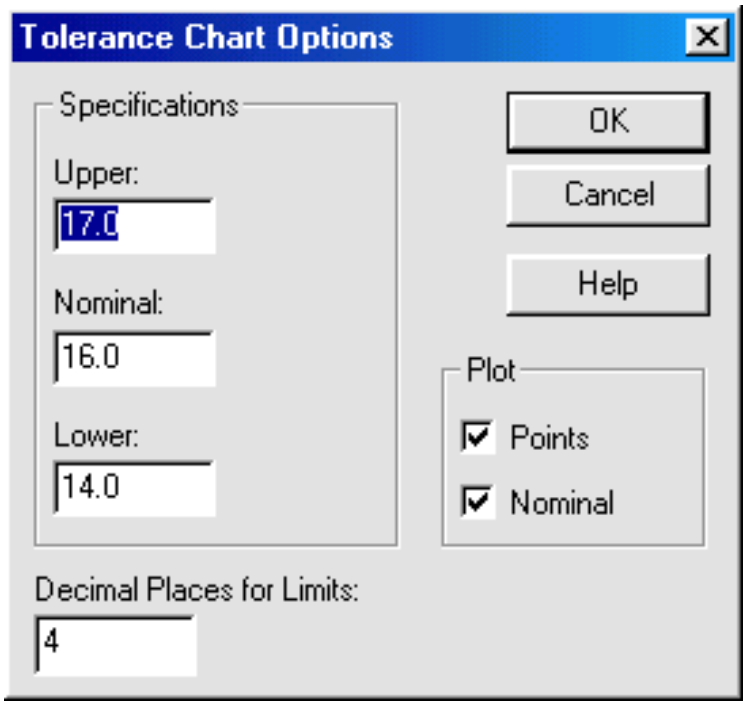

Figure 3-15. Tolerance Chart Options Dialog Box

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point that is plotted on the control chart will remain inside the control limits as a function of the true process mean (see Figure 3-16). It is useful for judging the effectiveness of a control chart in detecting when a process drifts away from the target. The X-axis shows the shift in the average; the Y-axis the probability of not detecting the shift.

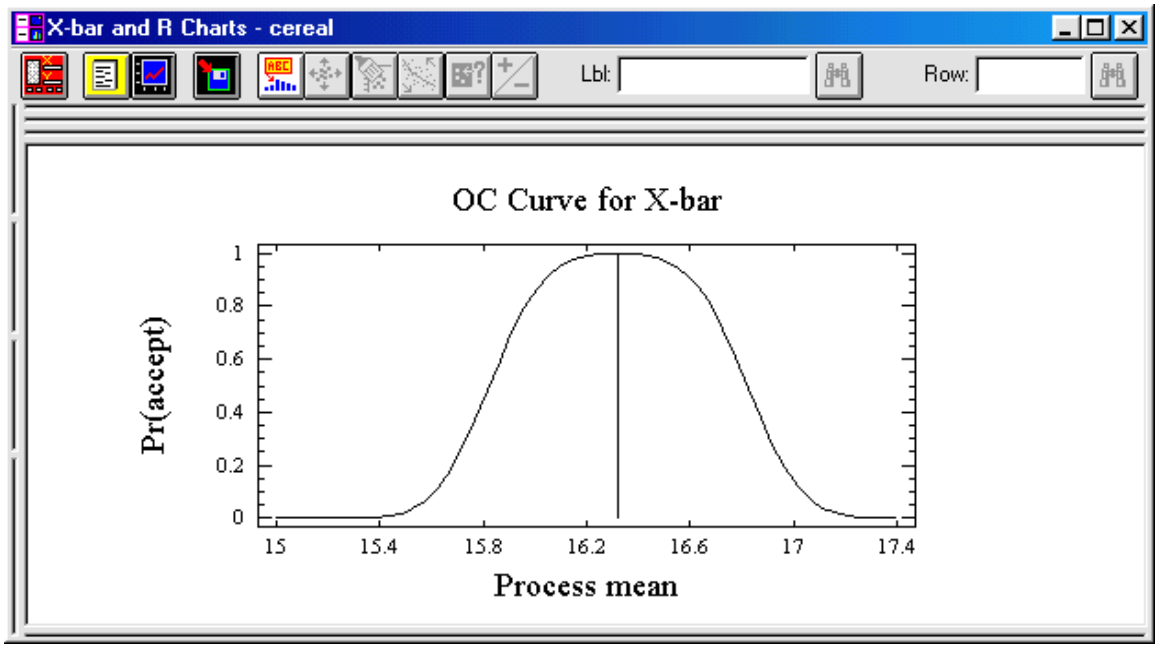

Figure 3-16. OC Curve

ARL Curve

The ARL Curve option creates a plot that shows the average run length (ARL) as a function of the process mean (see Figure 3-17). For example, if the process is actually running at Centerline, the chart should generate an out-of-control signal on an approximate average based on the number of samples. If the process moves away from the centerline, the average run length will change. The plot is helpful in choosing an adequate sampling plan to monitor the process.

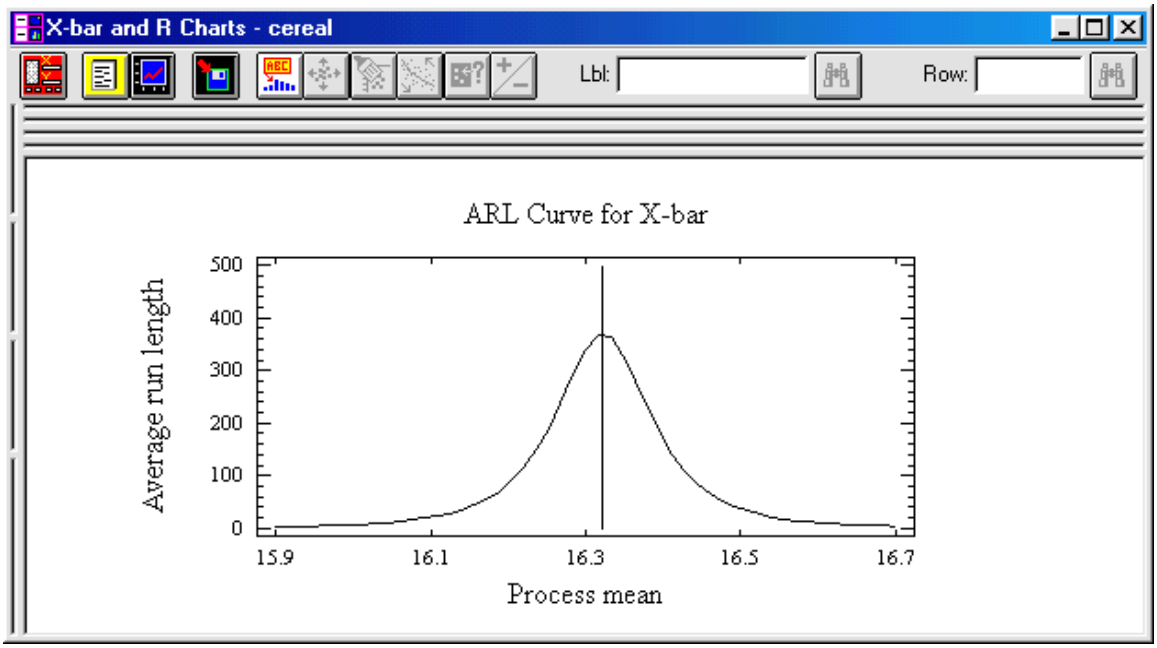

Figure 3-17. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to select the results you want to save. There are six selections: Means, Ranges, Sizes, Labels, Process Mean, and Process Sigma.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the X-bar and S Charts Analysis

X-bar and S charts were developed for the times when it is desirable to estimate the process standard deviation directly instead of using the range. For example, the S Chart is generally more appropriate than the R Chart when the subgroup size is eight or more. The process standard deviation, S, is more difficult to calculate, and usually is less sensitive in detecting special causes of variation when only a single value in a subgroup is unusual. These charts are also always used as a pair.

To Access the X-bar and S Charts Analysis

1. Choose SPECIAL... QUALITY CONTROL... VARIABLES CONTROL CHARTS... X-BAR AND S... from the Menu bar to display the X-bar and S Charts Analysis dialog box shown in Figure 3-18.

2. Complete the dialog box and click OK to display the Analysis Summary and the X-bar and S Chart in the Analysis window.

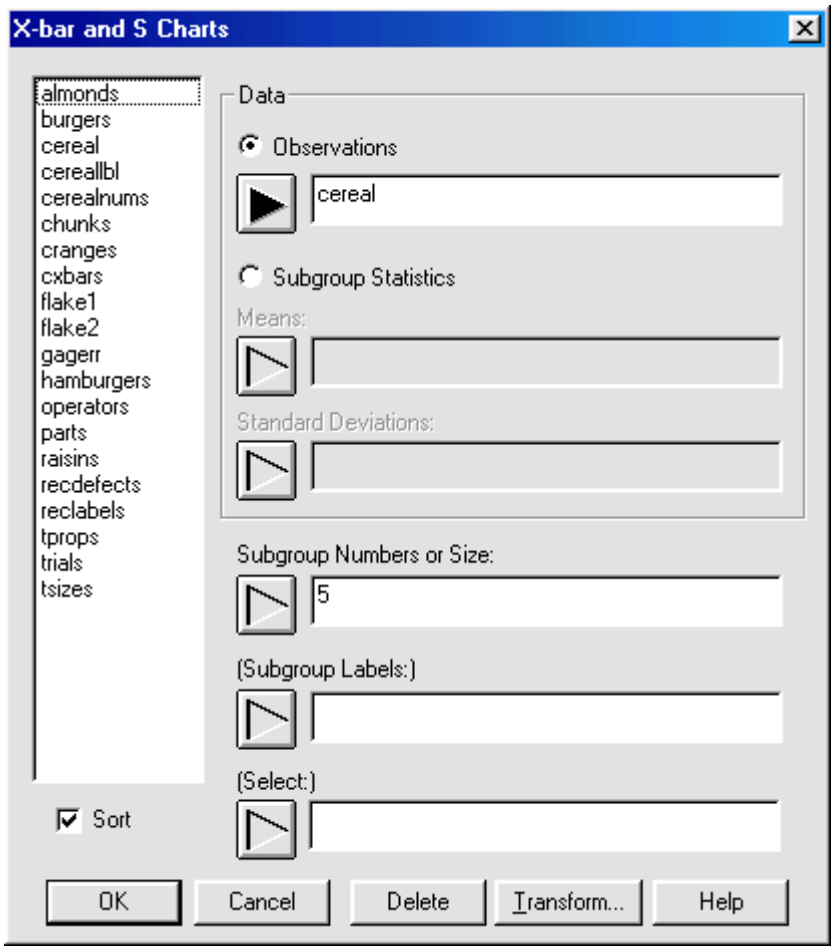

Figure 3-18. X-bar and S Charts Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option displays a summary of the analysis (see Figure 3-19). The analysis is designed to determine if the data are from a process that is in statistical control. The control charts are produced with the assumption that the data are from a normal distribution with the mean and standard deviation parameters.

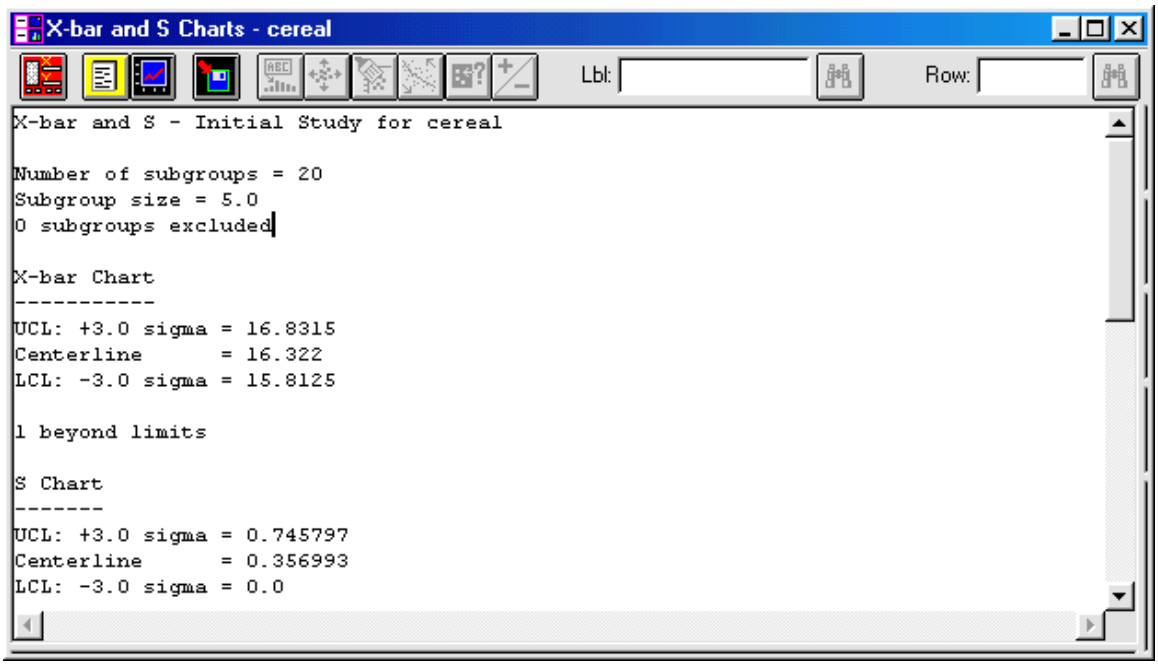

Figure 3-19. Analysis Summary

The summary also shows the type of study (Initial or Control to Standard), the variable name, the number of subgroups, the subgroup size, and the number of subgroups excluded from the study.

Values for the UCL, Centerline, and LCL and the number of subgroups beyond the limits are shown for the X-bar and S charts. Estimates are shown for the process mean and sigma, and the mean sigma.

Use the *X-bar and S Charts Options* dialog box to indicate if you want to perform an Initial study or a Control to Standard; to indicate if the subgroup data should be normalized to z-scores; and to indicate if the average subgroup size should be used to calculate the control limits (see Figure 3-20). You can also recalculate control limits for specified sets of subgroups. You can enter values for the Upper and Lower Sigma for the X-bar Control Limits and the Sigma Control Limits.

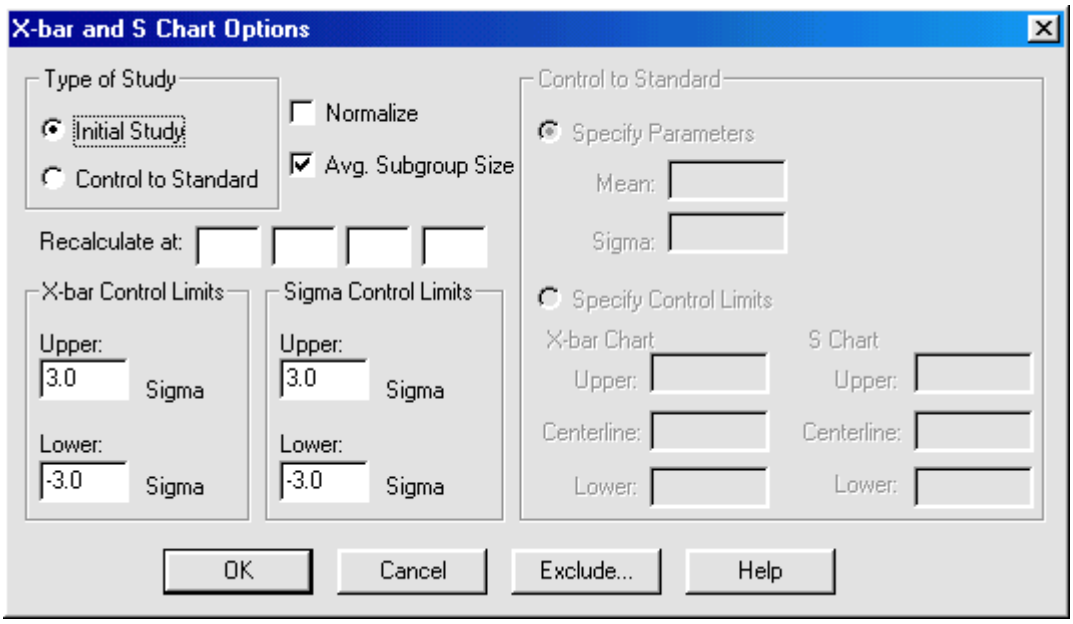

Figure 3-20. X-bar and S Charts Options Dialog Box

For a Control-to-Standard study, you can choose to either specify parameters (mean and sigma) or to specify control limits for the two charts: X-bar Chart and S Chart. For each of these you can enter values for the Upper, Centerline, and Lower limits.

Use the Exclude... command on the dialog box to choose the subgroups you want to exclude from the analysis. When you click the button, the Exclude/Include Options dialog box displays. See Figure 3-4 for an example of this dialog box.

Subgroup Reports

The Subgroup Reports option creates a table that displays the values that will be plotted on the control chart (see Figure 3-21). Points that are beyond the limits are noted with an asterisk; points that are excluded are noted by an X.

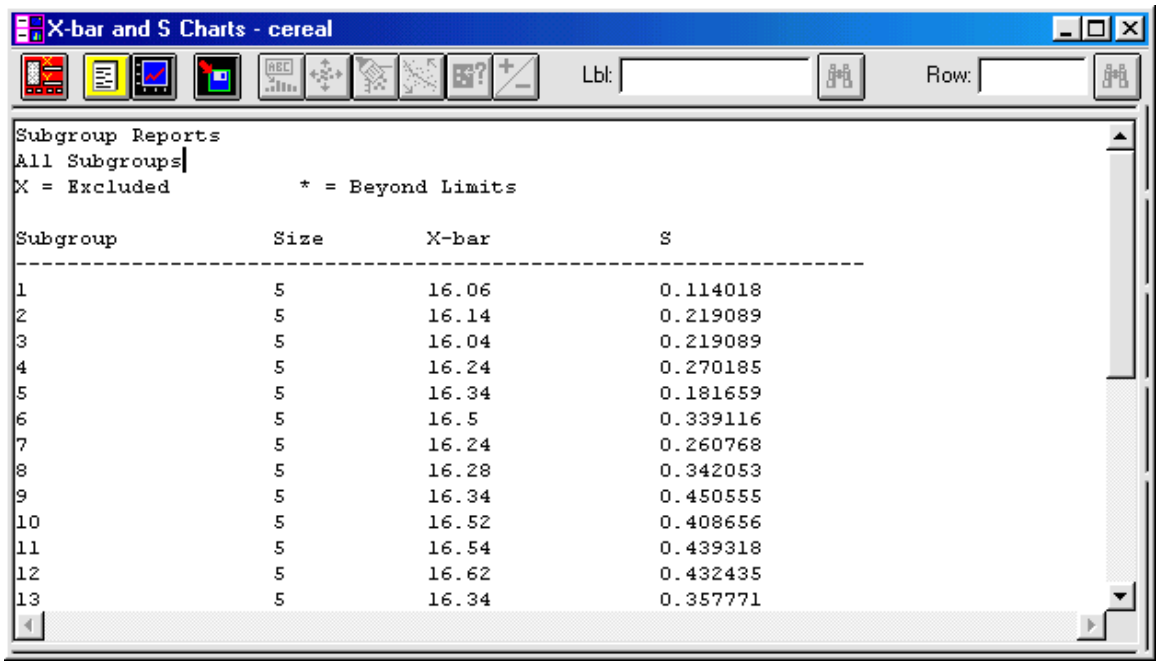

Figure 3-21. Subgroup Reports

Use the *Subgroup Reports Options* dialog box to choose the type of reports that will be included: All Subgroups, Subgroups Beyond Limits, X-bars Beyond Limits, Sigmas Beyond Limits, or Excluded Subgroups. See Figure 3-6 for an example of this dialog box.

Runs Tests

The Runs Tests option searches for and identifies any unusual patterns in the data (see Figure 3-22). The tests are helpful in detecting processes that are slowly drifting away from the target (even though no points may fall outside the control limits). A nonrandom pattern indicates that a process is out of control. The report displays the subgroup at which the unusual pattern was detected as well as the rule that was violated.

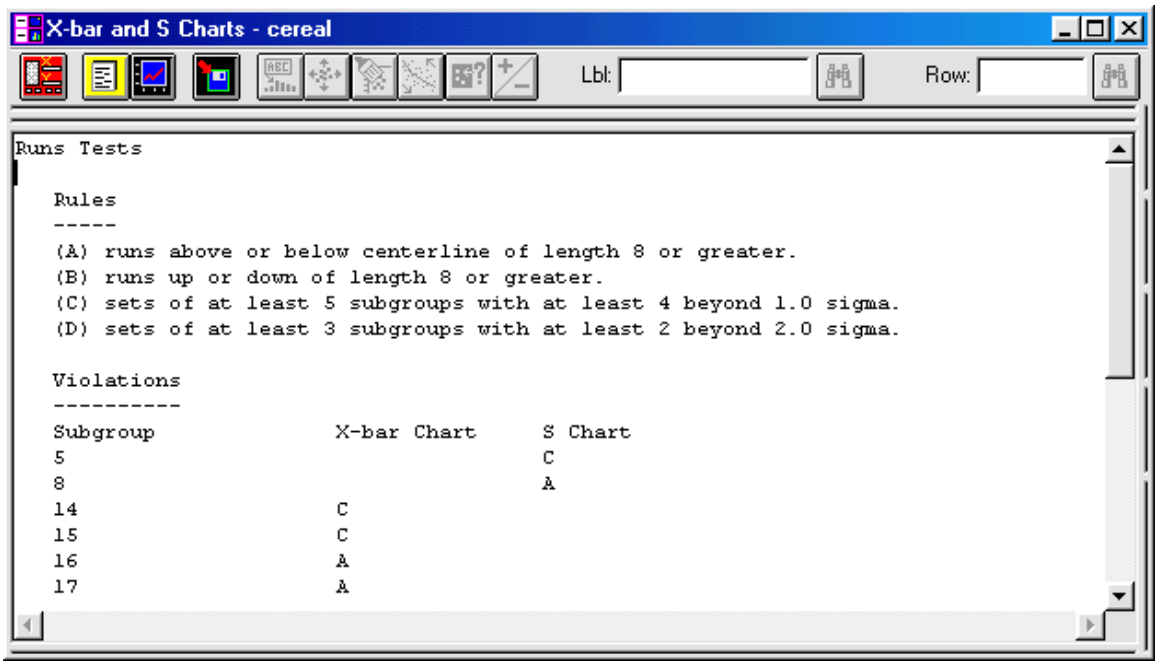

Figure 3-22. Runs Tests

Use the *Runs Tests Options* dialog box to indicate the guidelines for the tests and the violation rules. See Figure 3-8 for an example of this dialog box.

Capability Indices

The Capability Indices option calculates several process capability indices based on the estimated process mean and standard deviation (see Figure 3-23). These indices help determine the capability of a process to produce products that must meet a quality standard.

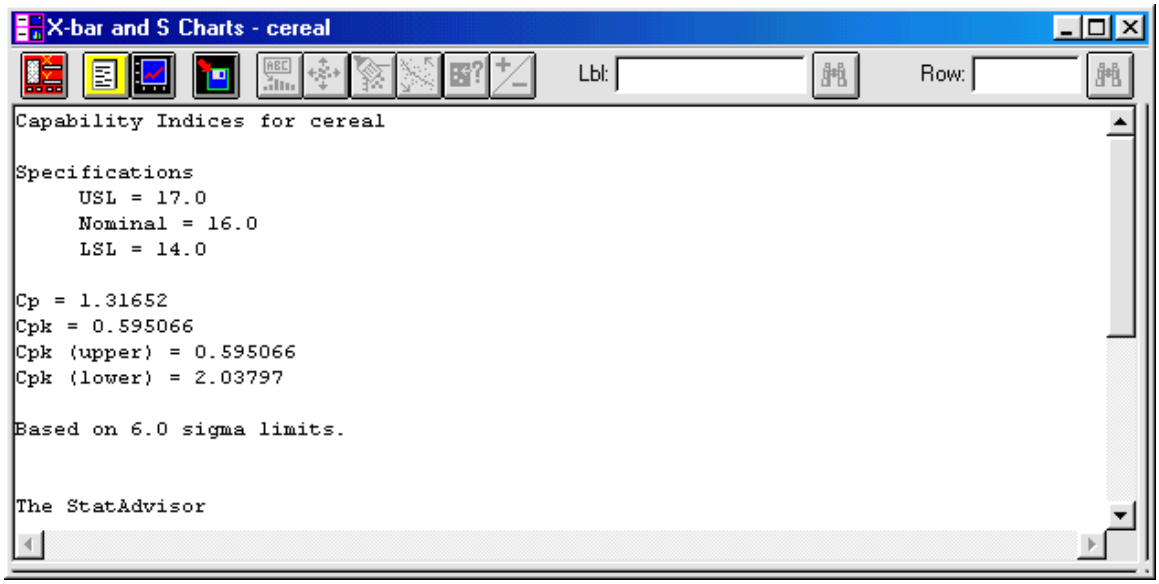

Figure 3-23. Capability Indices

Use the *Process Capability Indices Options* dialog box to choose the indices you want calculated, and to enter values for the USL, Nominal, and LSL specifications. See Figure 3-10 for an example of this dialog box.

Graphical Options

X-bar Chart

The X-bar Chart option creates a plot of the means for each of the subgroups (see Figure 3-24). A process is considered out of control if points are shown outside the control limits, or if points are shown within the control limits, but arranged in a nonrandom sequence.

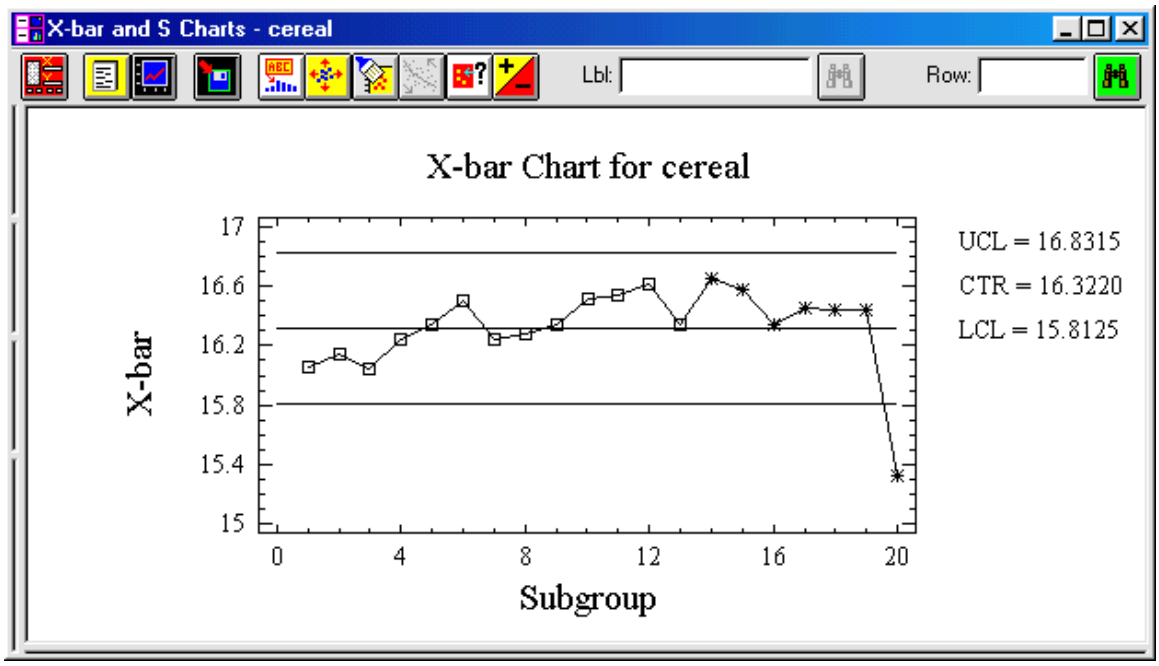

Figure 3-24. X-bar Chart

Use the *Control Chart Options* dialog box to indicate if outer and inner warning limits should be calculated, and if so, enter values for sigma. You also indicate if the moving average and exponentially weighted moving average should be calculated, and if so, enter values for the order and lambda, respectively. You also enter a value for the number of decimal places to be used for displaying the limits, and indicate if you want the rule violations noted. See Figure 3-12 for an example of this dialog box.

S Chart

The S Chart option creates a plot that shows the standard deviations for each of the subgroups (see Figure 3-25). It indicates if any points are beyond the control limits. A process is out of control if points are shown outside the control limits, or if points are within the control limits, but arranged in a nonrandom sequence.

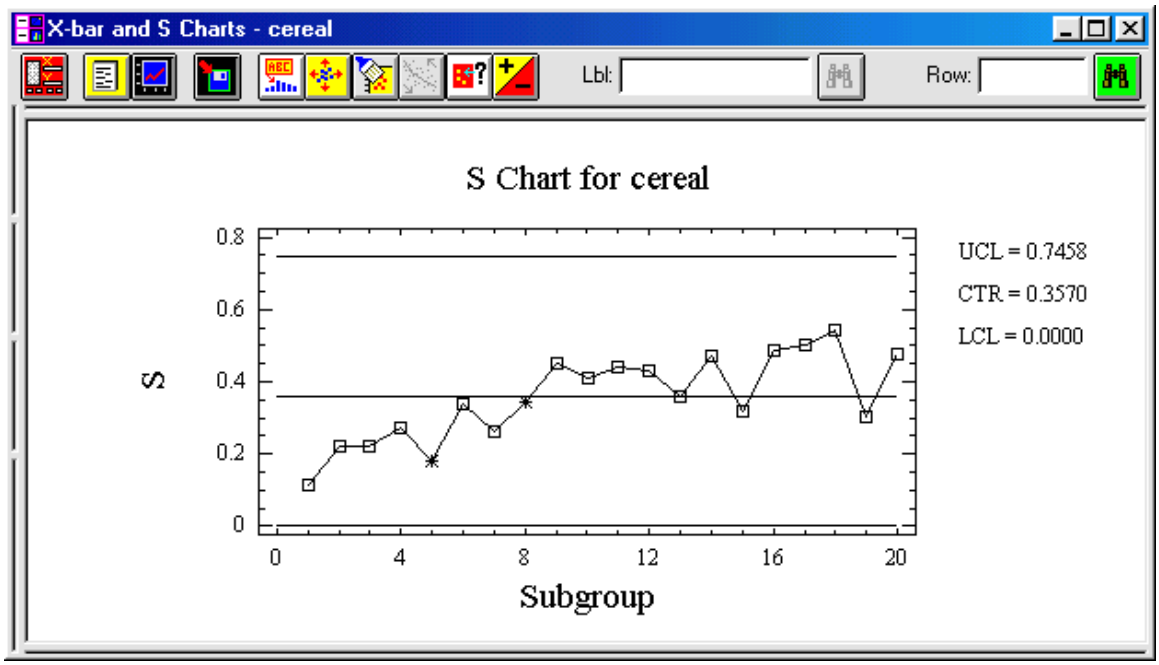

Figure 3-25. S Chart

Use the *Control Chart Options* dialog box to indicate if outer and inner warning limits should be calculated, and if so, enter values for sigma. You also indicate if the moving average and exponentially weighted moving average should be calculated, and if so, enter values for the order and lambda, respectively. You also enter a value for the number of decimal places to be used for displaying the limits, and indicate if you want the rule violations noted. See Figure 3-12 for an example of this dialog box.

Tolerance Chart

The Tolerance Chart option creates a plot of the individual values for the variable, arranged by subgroup (see Figure 3-26). A horizontal line shows the grand mean of the observations, while a vertical line shows the subgroup ranges. You can include specification limits on the chart.

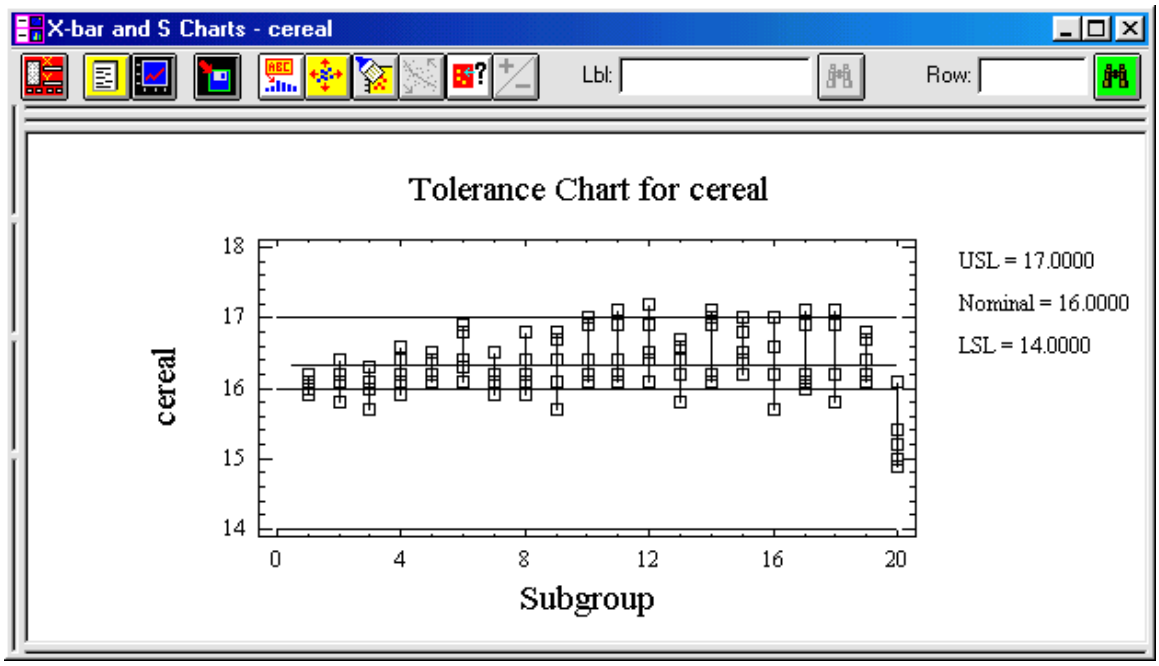

Figure 3-26. Tolerance Chart

Use the *Tolerance Chart Options* dialog box to enter values for the Upper, Nominal, and Lower specifications, to enter the number of decimal places that should be used for displaying the limits, and to indicate if points or the nominal specification line will display on the plot. See Figure 3-15 for an example of this dialog box.

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point that is plotted on the control chart will remain inside the control limits as a function of the true process mean (see Figure 3-27). It is useful for judging the effectiveness of a control chart in detecting when a process drifts away from the target. The X-axis shows the shift in the average; the Y-axis the probability of not detecting the shift.

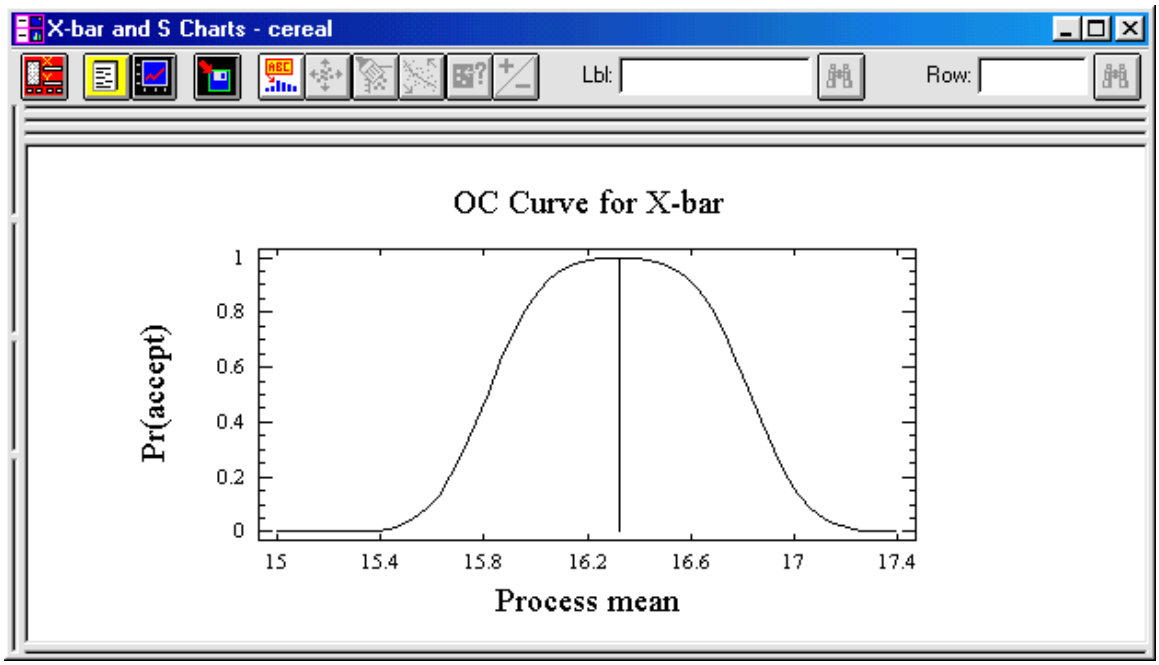

Figure 3-27. OC Curve

ARL Curve

The ARL Curve option creates a plot that shows the average run length (ARL) as a function of the process mean (see Figure 3-28). For example, if the process is actually running at centerline, the chart should generate an out-of-control signal on an approximate average based on the number of samples. If the process moves away from the centerline, the average run length will change. The plot is helpful in choosing an adequate sampling plan to monitor the process.

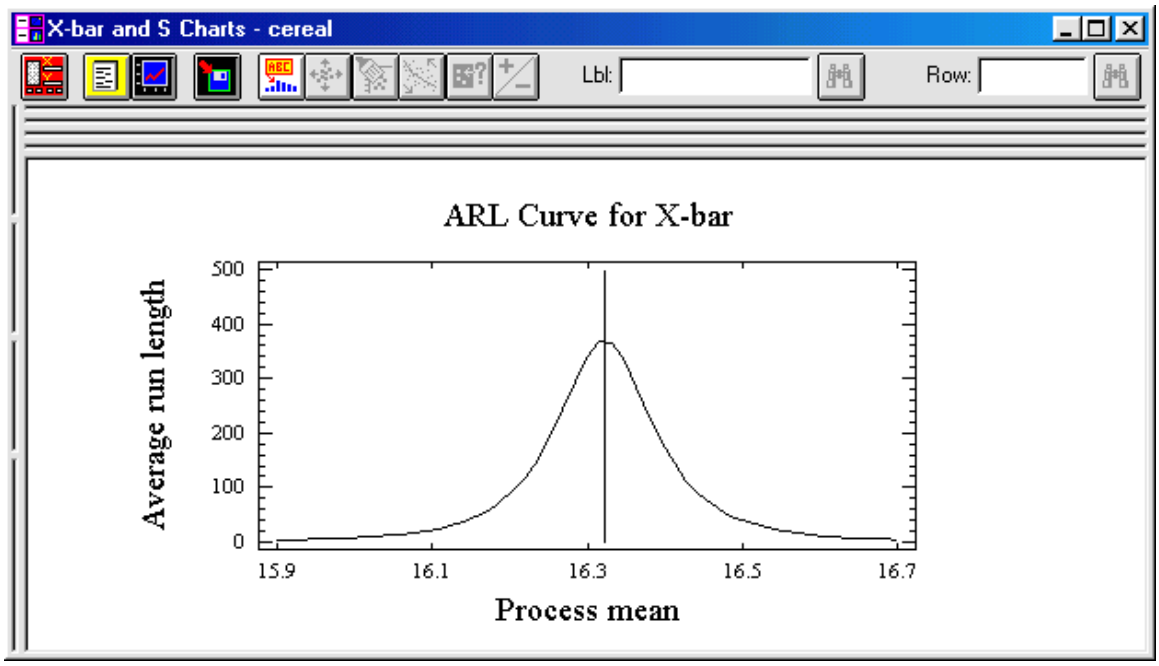

Figure 3-28. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to select the results you want to save. There are six selections: Means, Sigmas, Sizes, Labels, Process Mean, and Process Sigma.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the X-bar and S-Squared Charts Analysis

Montgomery (1997) notes that most quality engineers prefer to use either an R Chart or an S Chart to monitor process variability, using the S Chart with moderate to large sample sizes. Others recommend using a control chart that uses limits based on the sample variances — the S-Squared Chart.

To Access the X-bar and S-Squared Charts Analysis

1. Choose SPECIAL... QUALITY CONTROL... VARIABLES CONTROL CHARTS... X-BAR AND S-SQUARED... from the Menu bar to display the X-bar and S-Squared Charts Analysis dialog box shown in Figure 3-29.

2. Complete the dialog box and click OK to display the Analysis Summary and the X-bar and S-Squared Chart in the Analysis window.

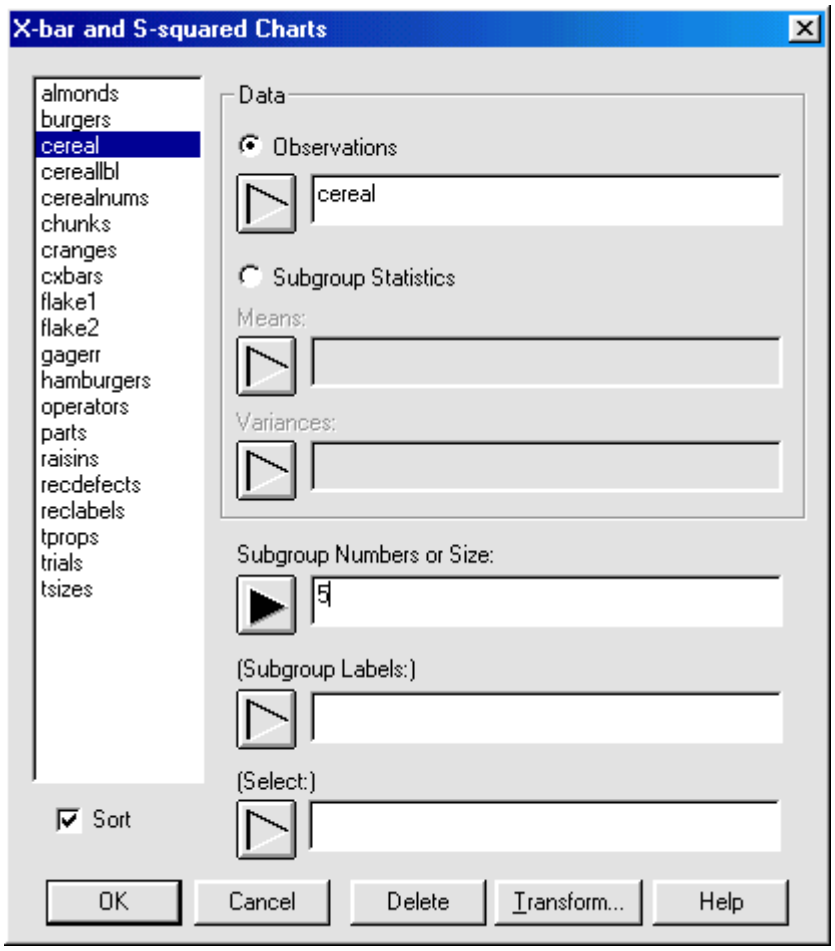

Figure 3-29. X-bar and S-Squared Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option displays a summary of the analysis (see Figure 3-30). The analysis is designed to determine if the data are from a process that is in statistical control. The control charts are produced with the assumption that the data are from a normal distribution with the mean and standard deviation parameters.

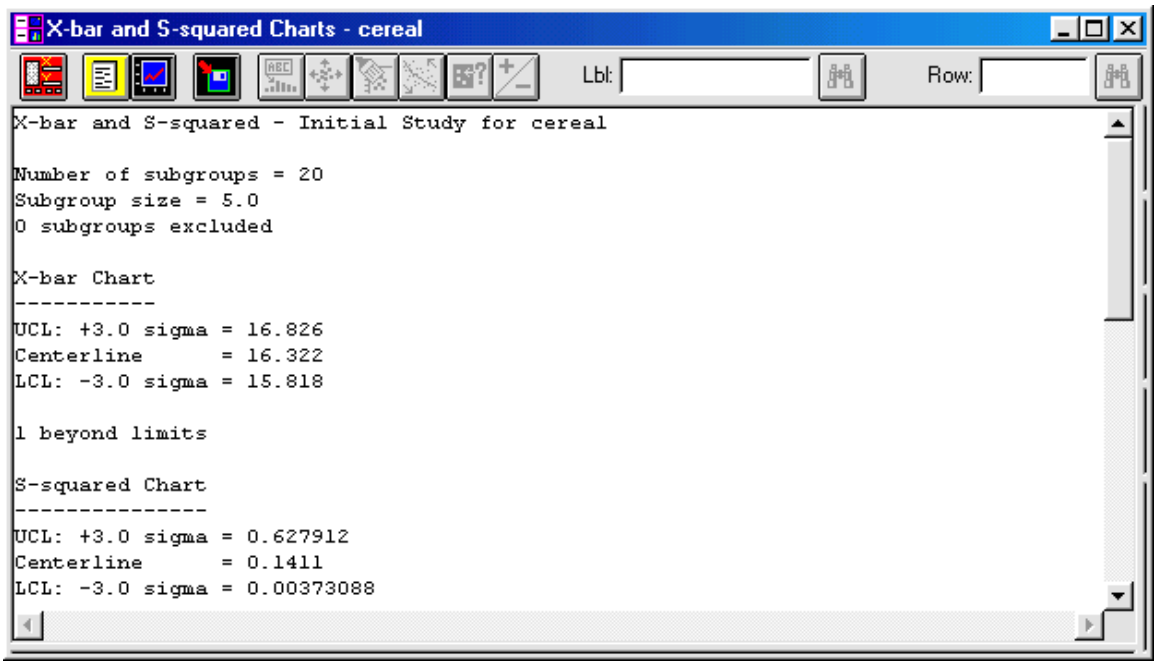

Figure 3-30. X-bar and S-Squared Analysis Summary

The summary also shows the type of study (Initial or Control to Standard), the variable name, the number of subgroups, the subgroup size, and the number of subgroups excluded from the study.

Values for the UCL, Centerline, and LCL and the number of subgroups beyond the limits are shown for the X-bar and S-Squared charts. Estimates are shown for the process mean and sigma, and the pooled variance.

Use the *X-bar and S-Squared Charts Options* dialog box to indicate if you want to perform an Initial study or a Control to Standard; to indicate if the average subgroup size should be used to calculate the control limits (see Figure 3-31). You can also recalculate control limits for specified sets of subgroups. You can enter values for the Upper and Lower Sigma for the X-bar Control Limits and the S-Squared Control Limits.

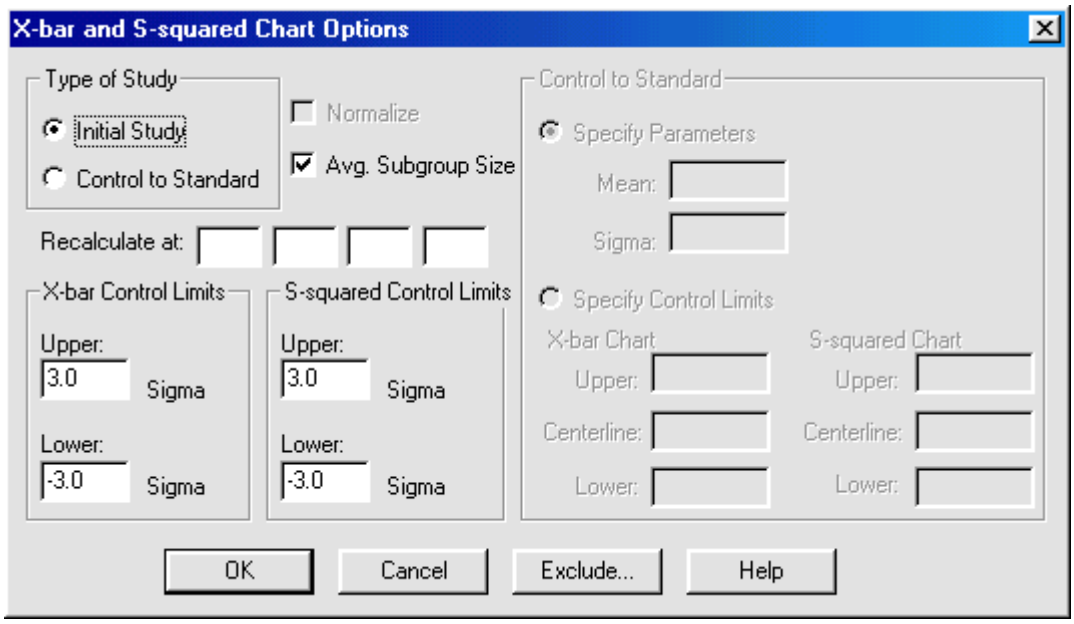

Figure 3-31. X-bar and S-Squared Chart Options Dialog Box

For a Control-to-Standard study, you can choose to either specify parameters (mean and sigma) or to specify control limits for the two charts: X-bar Chart and S-Squared Chart. For each of these you can enter values for the Upper, Centerline, and Lower limits.

Use the Exclude... command on the dialog box to choose the subgroups you want to exclude from the analysis. When you click the button, the Exclude/Include Options dialog box displays. See Figure 3-4 for an example of this dialog box.

Subgroup Reports

The Subgroup Reports option creates a table that displays the values that will be plotted on the control chart (see Figure 3-32). Points that are beyond the limits are noted with an asterisk; points that are excluded are noted by with X.

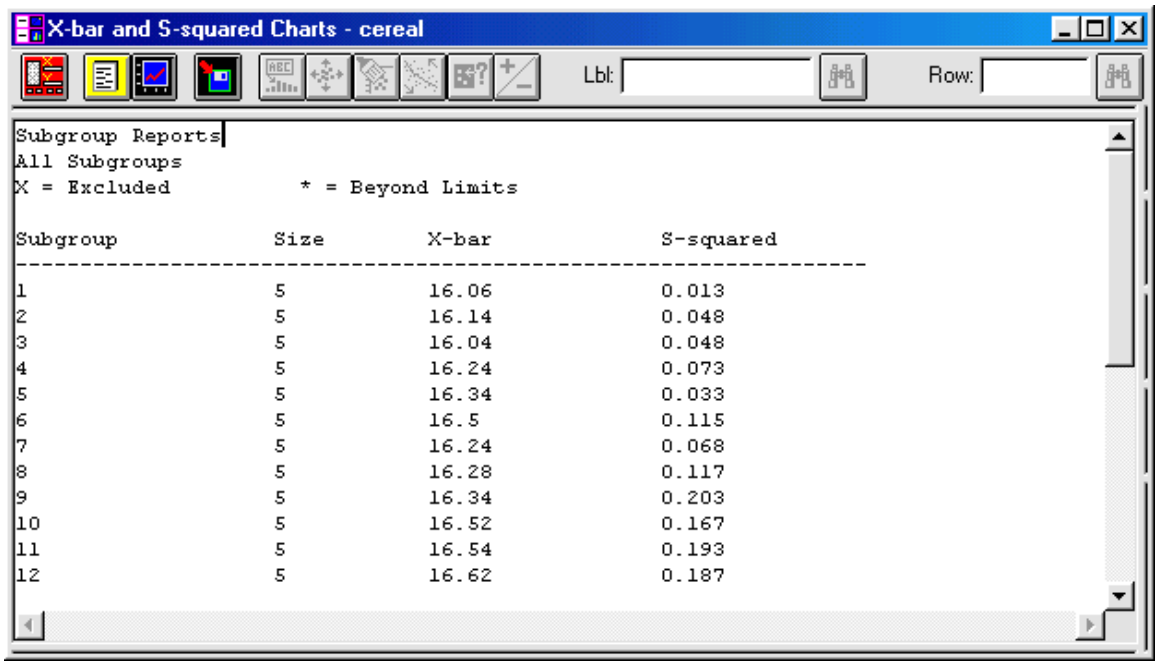

Figure 3-32. Subgroup Reports

Use the *Subgroup Reports Options* dialog box to choose the type of reports that will be included: All Subgroups, Subgroups Beyond Limits, X-bars Beyond Limits, Variances Beyond Limits, or Excluded Subgroups. See Figure 3-6 for an example of this dialog box.

Runs Tests

The Runs Tests option searches for and identifies any unusual patterns in the data (see Figure 3-33). The tests are helpful in detecting processes that are slowly drifting away from the target (even though no points may fall outside the control limits). A nonrandom pattern indicates that a process is out of control. The report displays the subgroup at which the unusual pattern was detected as well as the rule that was violated.

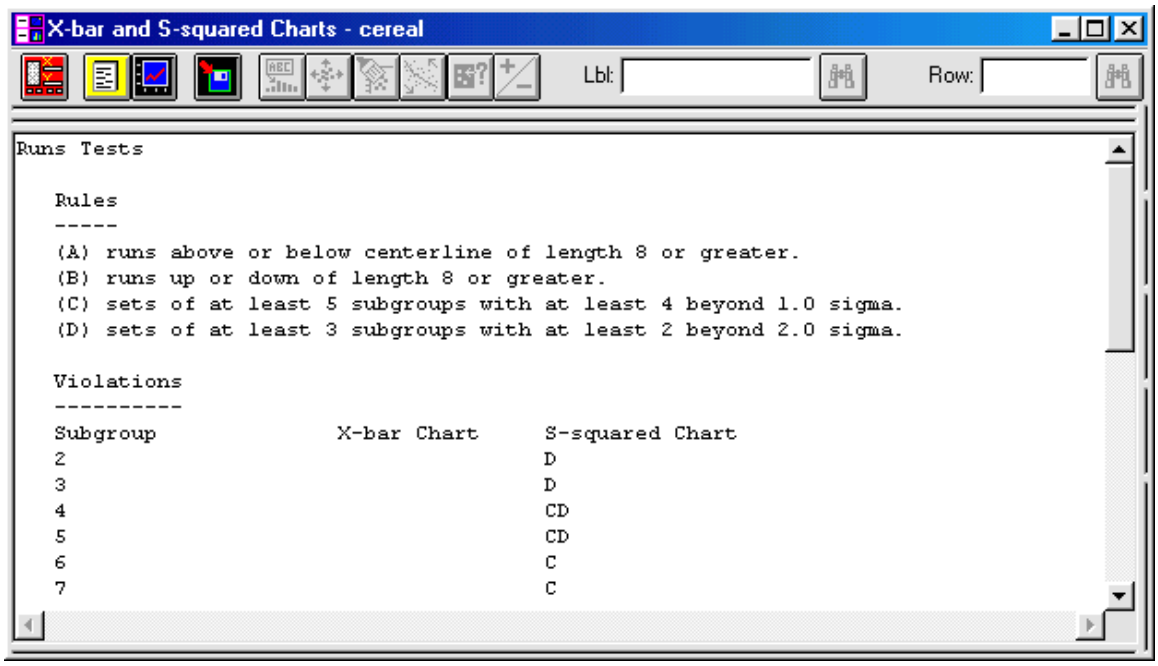

Figure 3-33. Runs Tests

Use the *Runs Tests Options* dialog box to indicate the guidelines for the tests and the violation rules. See Figure 3-8 for an example of this dialog box.

Capability Indices

The Capability Indices option creates capability indices you choose that are based on the estimated process mean and standard deviation (see Figure 3-34). Sigma limits of 6.0 are used to calculate the indices. The values help to determine the capability of a process to produce products that meet a standard.

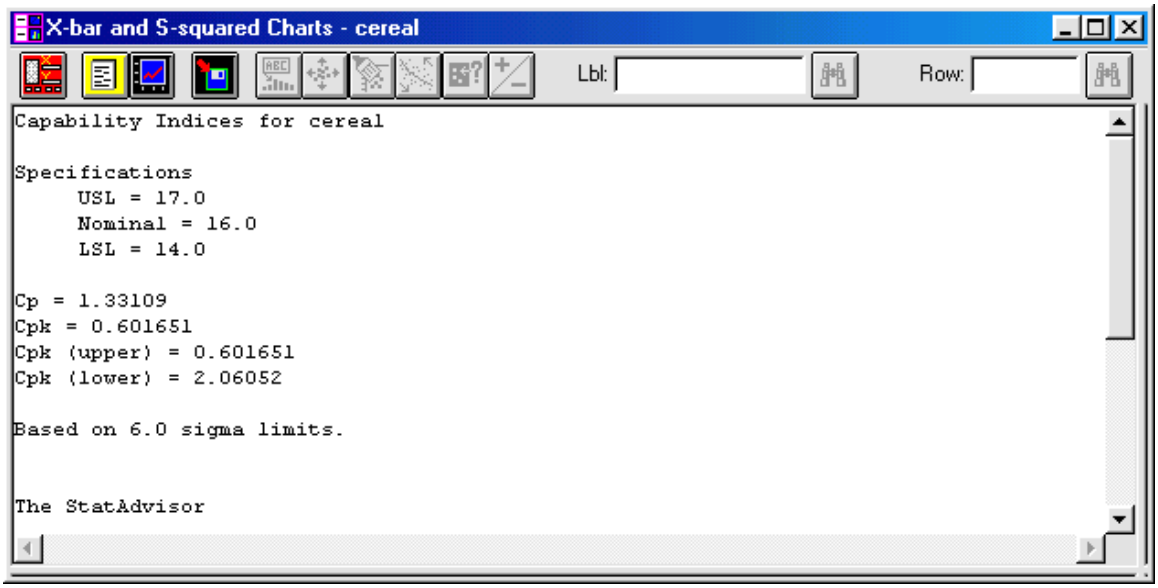

Figure 3-34. Capability Indices

Use the *Process Capability Indices Options* dialog box to choose the indices you want calculated, and to enter values for the USL, Nominal, and LSL specifications. See Figure 3-10 for an example of this dialog box.

Graphical Options

X-bar Chart

The X-bar Chart option creates a plot of the means for each of the subgroups (see Figure 3-35). A process is considered out of control if points are shown outside the control limits, or if points are shown within the control limits, but arranged in a nonrandom sequence.

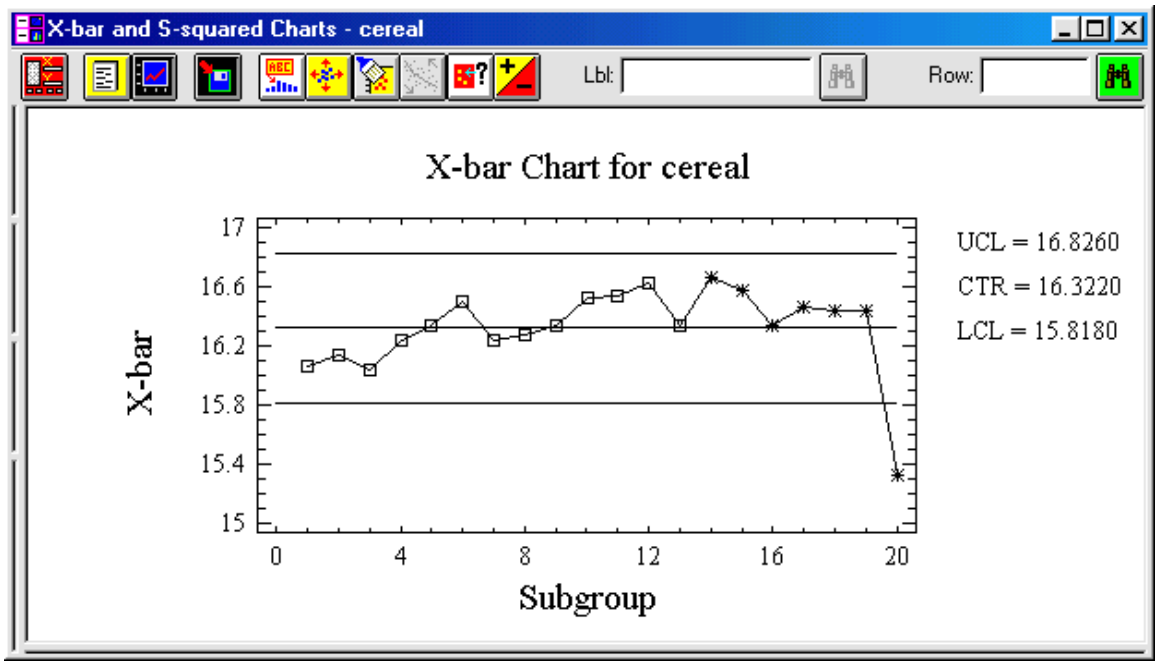

Figure 3-35. X-bar Chart

Use the *Control Chart Options* dialog box to indicate if outer and inner warning limits should be calculated, and if so, enter values for sigma. You also indicate if the moving average and exponentially weighted moving average should be calculated, and if so, enter values for the order and lambda, respectively. You also enter a value for the number of decimal places to be used for displaying the limits, and indicate if you want the rule violations noted. See Figure 3-12 for an example of this dialog box.

S-Squared Chart

The S-Squared Chart option creates a plot that shows the variances for each of the subgroups (see Figure 3-36). It indicates if any points are beyond the control limits. A process is out of control if points are shown outside the control limits, or if points are within the control limits, but arranged in a nonrandom sequence.

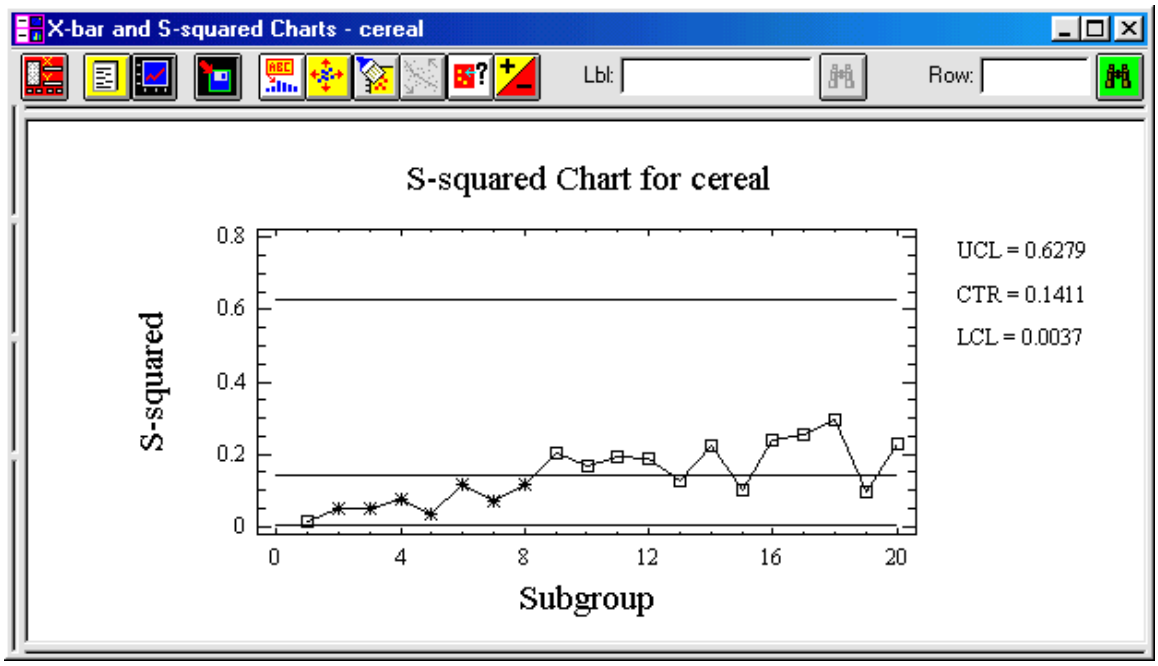

Figure 3-36. S-Squared Chart

Use the *Control Chart Options* dialog box to indicate if outer and inner warning limits should be calculated, and if so, enter values for sigma. You also indicate if the moving average and exponentially weighted moving average should be calculated, and if so, enter values for the order and lambda, respectively. You also enter a value for the number of decimal places to be used for displaying the limits, and indicate if you want the rule violations noted. See Figure 3-12 for an example of this dialog box.

Tolerance Chart

The Tolerance Chart option creates a plot of the individual values for the variable, arranged by subgroup (see Figure 3-37). A horizontal line shows the grand mean of the observations, while a vertical line shows the subgroup ranges. You can include specification limits on the chart.

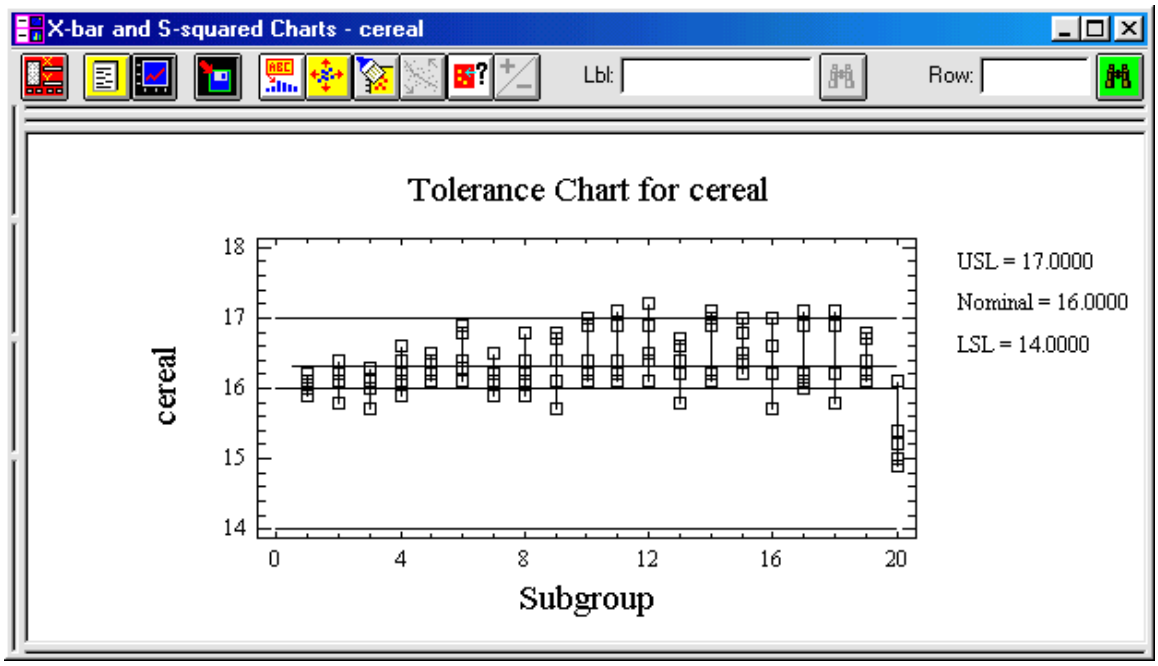

Figure 3-37. Tolerance Chart

Use the *Tolerance Chart Options* dialog box to enter values for the Upper, Nominal, and Lower specifications, to enter the number of decimal places that should be used for displaying the limits, and to indicate if points or the nominal specification line will display on the plot. See Figure 3-15 for an example of this dialog box.

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point that is plotted on the control chart will remain inside the control limits as a function of the true process mean (see Figure 3-38). It is useful for judging the effectiveness of a control chart in detecting when a process drifts away from the target. The X-axis shows the shift in the average; the Y-axis the probability of not detecting the shift.

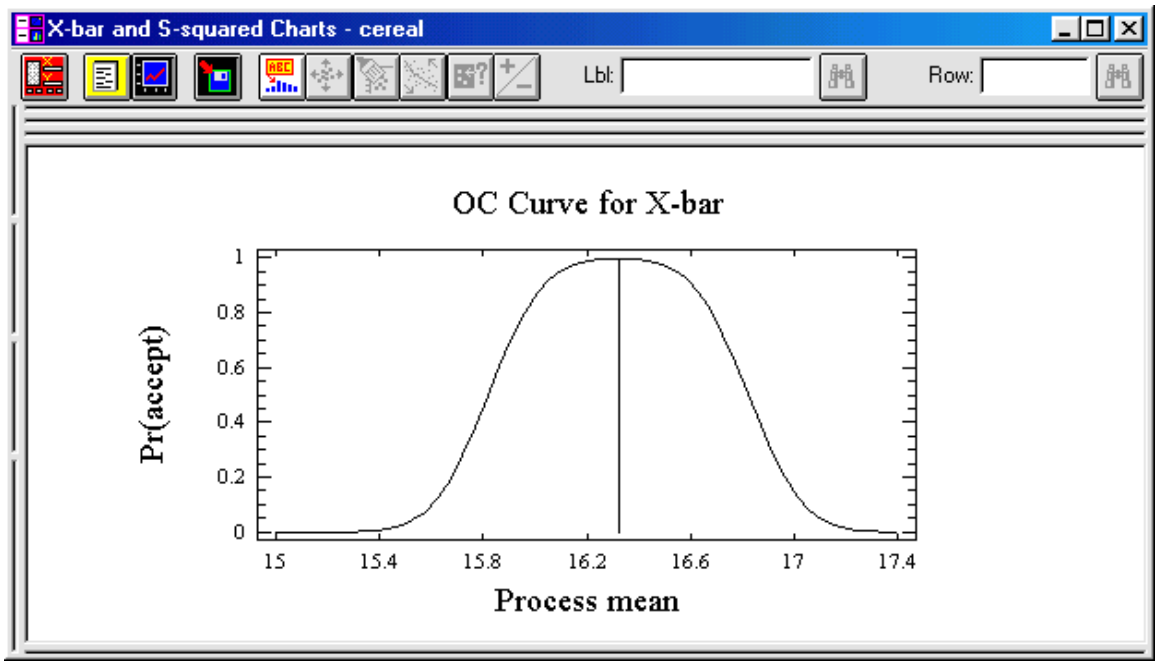

Figure 3-38. OC Curve

ARL Curve

The ARL Curve option creates a plot that shows the average run length (ARL) as a function of the process mean (see Figure 3-39). For example, if the process is actually running at centerline, the chart should generate an out-of-control signal on an approximate average based on the number of samples. If the process moves away from the centerline, the average run length will change. The plot is helpful in choosing an adequate sampling plan to monitor the process.

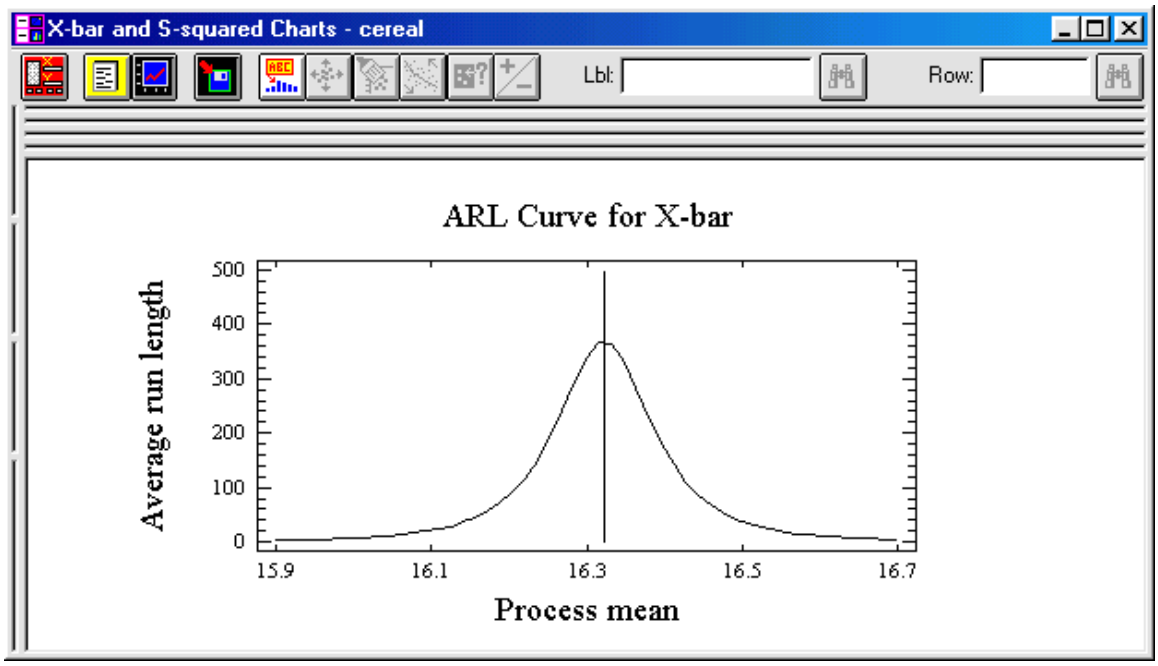

Figure 3-39. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to select the results you want to save. There are six selections: Means, Variances, Sizes, Labels, Process Mean, and Process Sigma.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the Individuals Charts Analysis

There are instances when it is necessary for process control to be based on individual readings, instead of subgroups. This usually happens when the sample is made up on a single unit. Montgomery (1997) provides some examples; for example, when:

- automated inspection and measurement technology is used and every unit that is manufactured is analyzed

- the production rate is very slow and it is inconvenient to let sample sizes of n > 1 accumulate before they are analyzed

- repeat measurements on a process differ only because of laboratory or analysis error (chemical processes).

The control process uses the moving range of two successive observations to estimate the variability.

To Access the Individuals Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... VARIABLES CONTROL CHARTS... INDIVIDUALS... from the Menu bar to display the Individuals Chart Analysis dialog box shown in Figure 3-40.

2. Complete the dialog box and click OK to display the Analysis Summary and the Individuals Chart in the Analysis window.

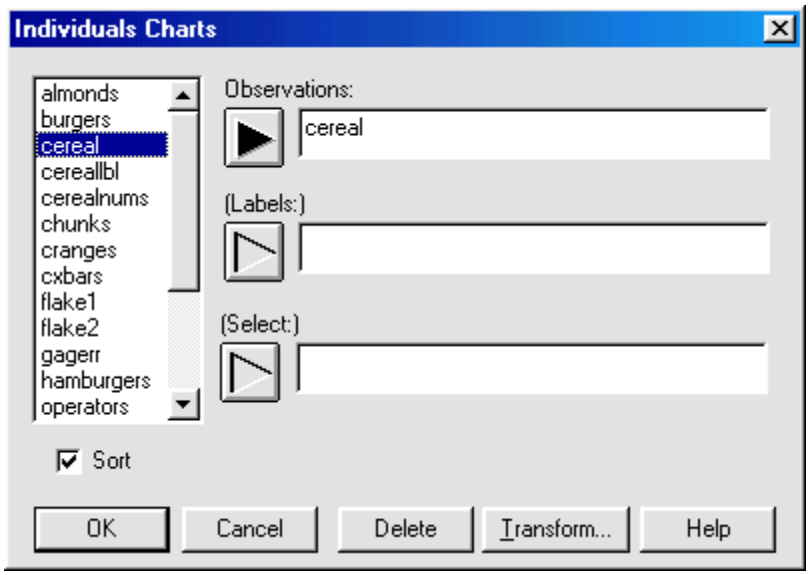

Figure 3-40. Individuals Charts Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option displays a summary of the analysis (see Figure 3-41). The analysis is designed to determine if the data are from a process that is in statistical control. The control charts are produced with the assumption that the data are from a normal distribution with the mean and standard deviation parameters.

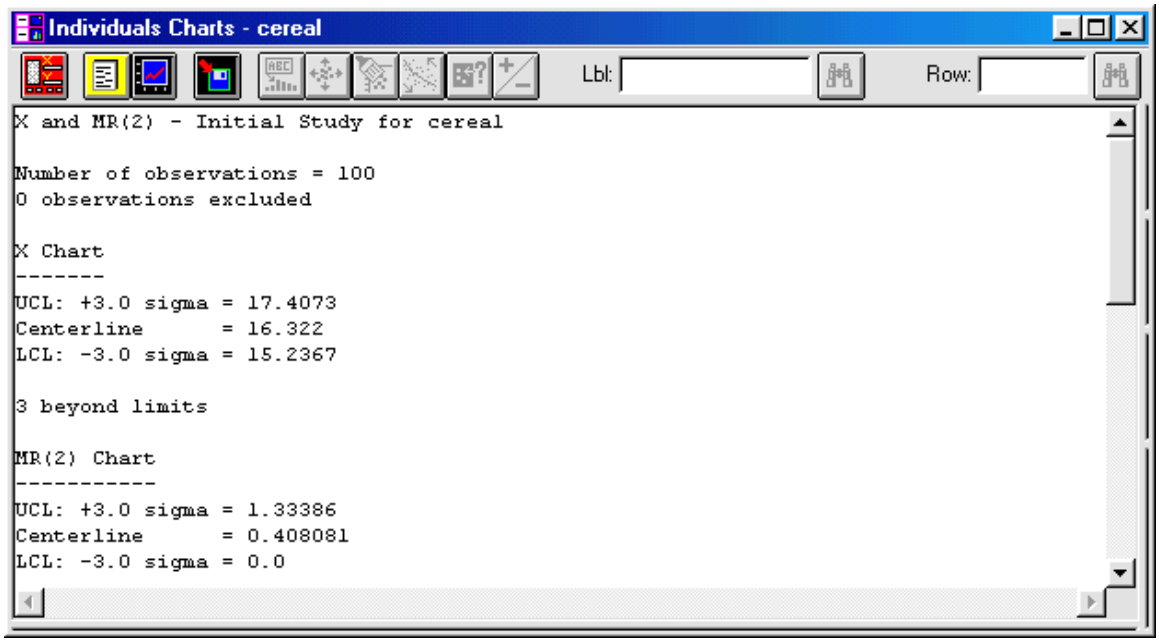

Figure 3-41. Analysis Summary

The summary also shows the type of study (Initial or Control to Standard), the variable name, the number of observations and the number of observations excluded from the study. Values for the UCL, Centerline, and LCL and the number of observations beyond the limits are shown for the X and MR(2) charts. Estimates are shown for the process mean and sigma, and the mean MR(2).

Use the *Individuals Charts Options* dialog box to indicate if you want to perform an Initial study or a Control to Standard; and to indicate if the data should be normalized to z-scores (see Figure 3-42). You can also recalculate control limits for specified sets of observations. You can enter values for the Upper and Lower Sigma for the X Control Limits and the MR(2) Control Limits.

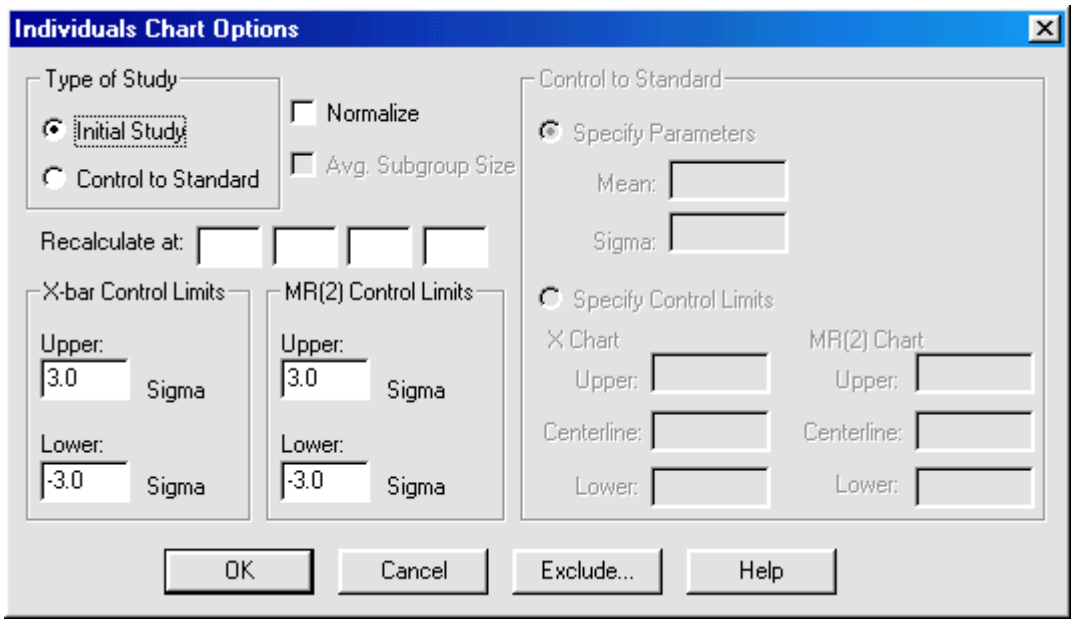

Figure 3-42. Individuals Charts Options Dialog Box

For a Control-to-Standard study, you can choose to either specify parameters (mean and sigma) or to specify control limits for the two charts: X Chart and MR(2) Chart. For each of these you can enter values for the Upper, Centerline, and Lower limits.

Use the Exclude... command on the dialog box to choose the observations you want to exclude from the analysis. When you click the button, the Exclude/Include Options dialog box displays. See Figure 3-4 for an example of this dialog box.

Individuals Chart Reports

The Individuals Chart Reports option creates a table that displays the values that will be plotted on the control chart (see Figure 3-43). Points that are beyond the limits are noted with an asterisk; points that are excluded are noted by an X.

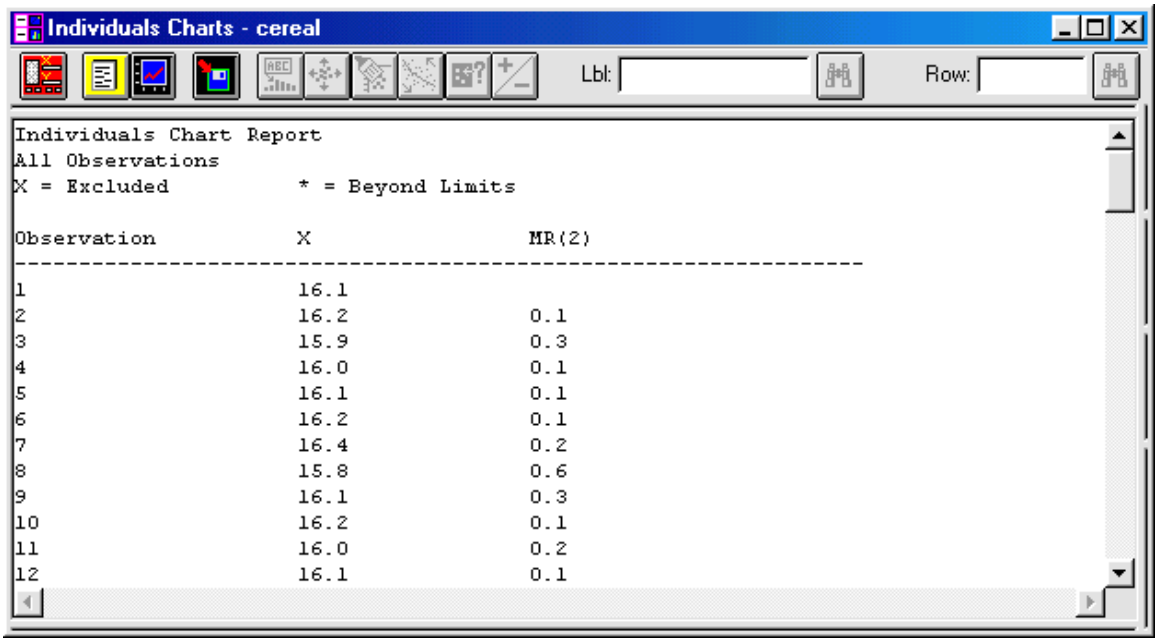

Figure 3-43. Individuals Chart Reports

Use the *Individuals Chart Report Options* dialog box to choose the type of reports that will be included: All Observations, Observations Beyond Limits, X Beyond Limits, MR(2) Beyond Limits, or Excluded Observations (see Figure 3-44).

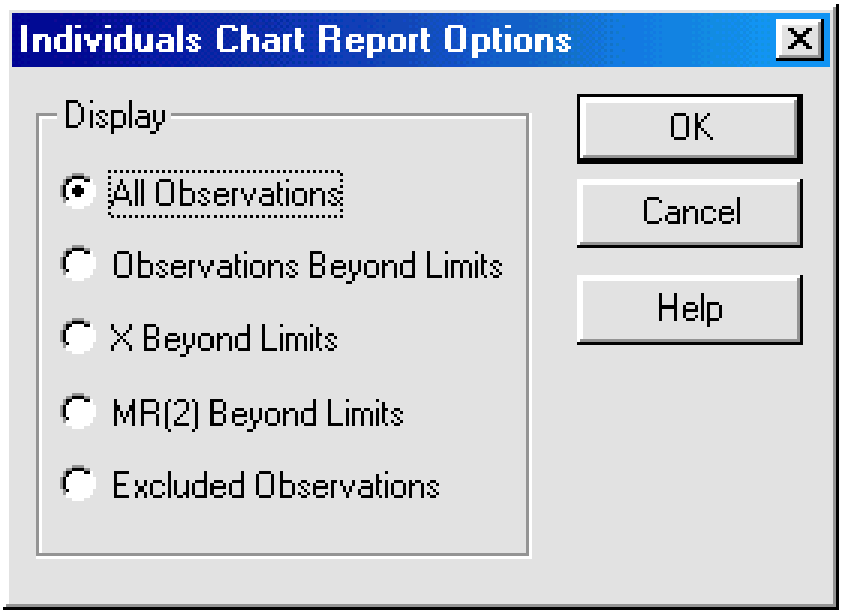

Figure 3-44. Individuals Chart Reports Options Dialog Box

Runs Tests

The Runs Tests option searches for and identifies any unusual patterns in the data (see Figure 3-45). The tests are helpful in detecting processes that are slowly drifting away from the target (even though no points may fall outside the control limits). A nonrandom pattern indicates that a process is out of control. The report displays the subgroup at which the unusual pattern was detected as well as the rule that was violated.

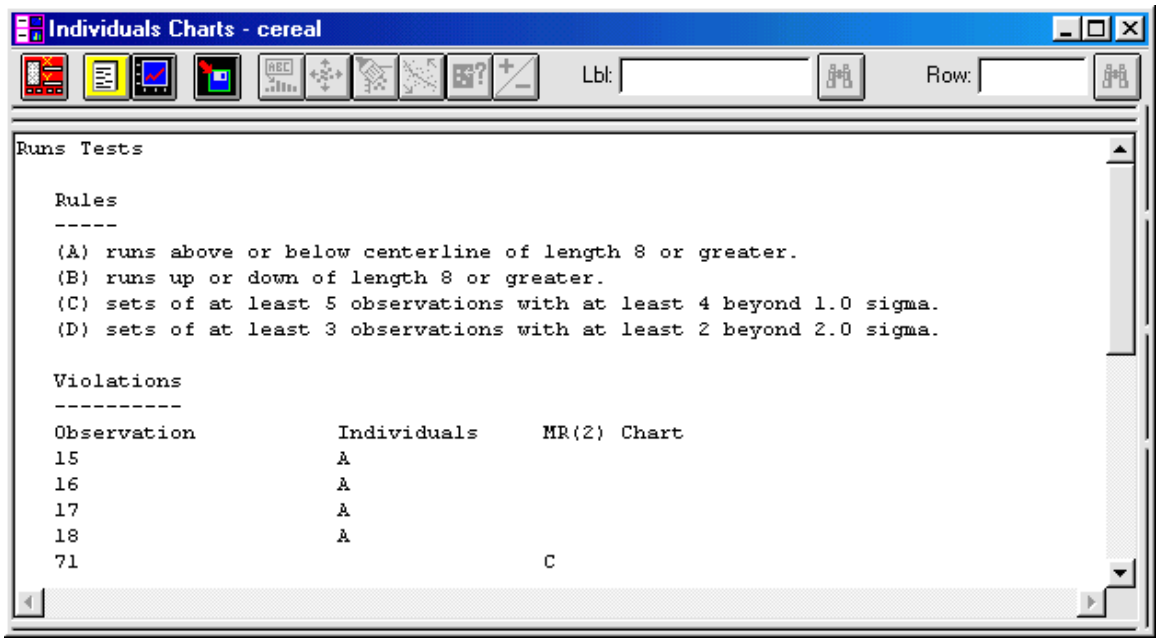

Figure 3-45. Runs Tests

Use the *Runs Tests Options* dialog box to indicate the guidelines for the tests and the violation rules. See Figure 3-8 for an example of this dialog box.

Capability Indices

The Capability Indices option creates capability indices you choose that are based on the estimated process mean and standard deviation (see Figure 3-46). Sigma limits of 6.0 are used to calculate the indices. The values help to determine the capability of a process to produce products that meet a standard.

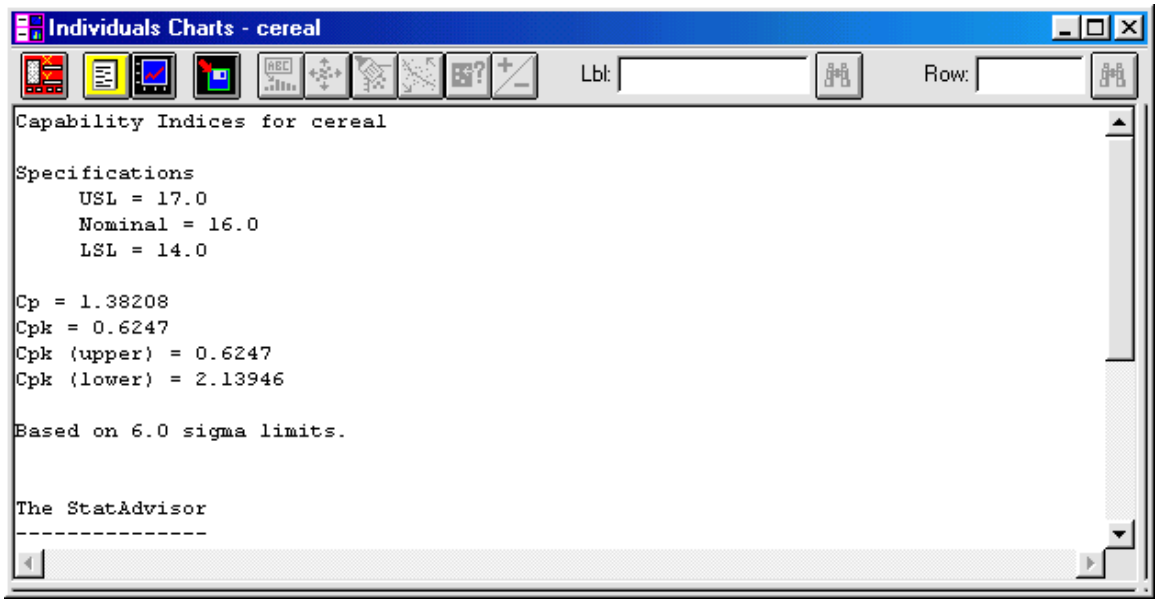

Figure 3-46. Capability Indices

Use the *Process Capability Indices Options* dialog box to choose the indices you want calculated, and to enter values for the USL, Nominal, and LSL specifications. See Figure 3-10 for an example of this dialog box.

Graphical Options

X Chart

The X Chart option creates a plot of the individual measurements (see Figure 3-47). A process is considered out of control if points are shown outside the control limits, or if points are shown within the control limits, but arranged in a nonrandom sequence.

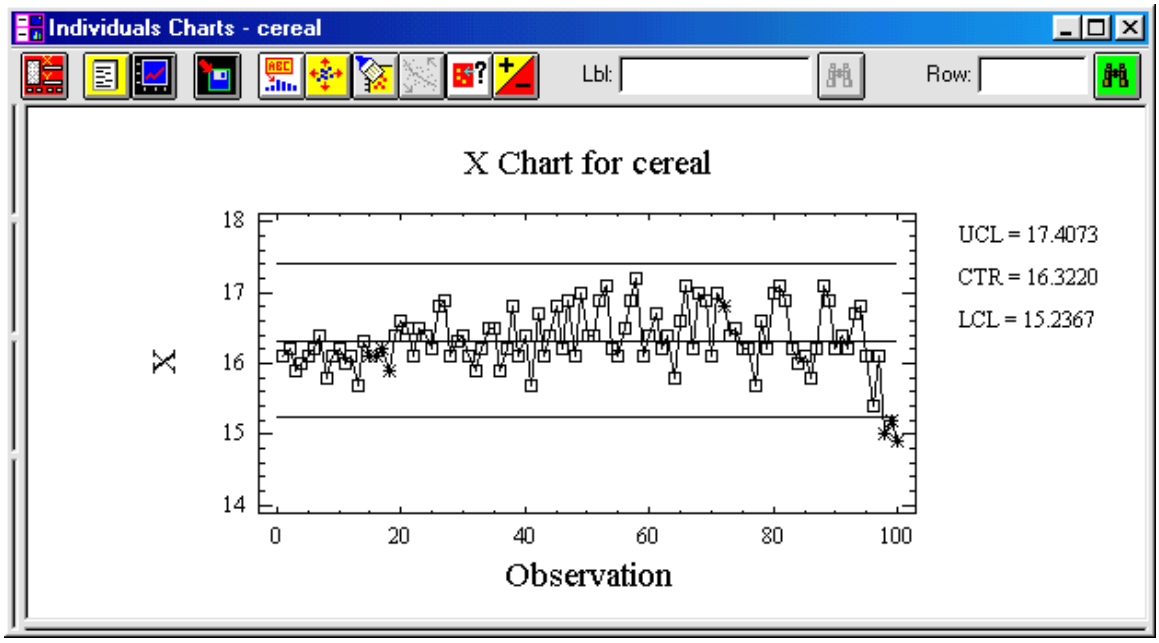

Figure 3-47. X Chart

Use the *Control Chart Options* dialog box to indicate if outer and inner warning limits should be calculated, and if so, enter values for sigma. You also indicate if the moving average and exponentially weighted moving average should be calculated, and if so, enter values for the order and lambda, respectively. You also enter a value for the number of decimal places to be used for displaying the limits, and indicate if you want the rule violations noted. See Figure 3-12 for an example of this dialog box.

MR(2) Chart

The MR(2) Chart option creates a plot of the moving ranges for each of the measurements (see Figure 3-48). It indicates if any points are beyond the control limits. A process is out of control if points are shown outside the control limits, or if points are within the control limits, but arranged in a nonrandom sequence.

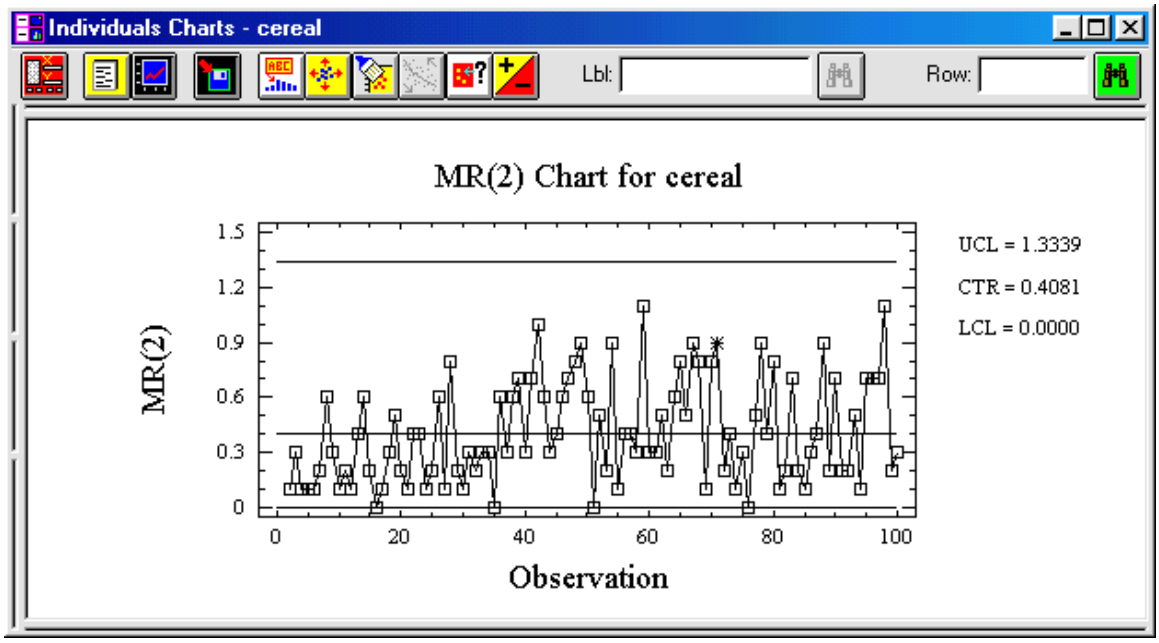

Figure 3-48. MR(2) Chart

Use the *Control Chart Options* dialog box to indicate if outer and inner warning limits should be calculated, and if so, enter values for sigma. You also indicate if the moving average and exponentially weighted moving average should be calculated, and if so, enter values for the order and lambda, respectively. You also enter a value for the number of decimal places to be used for displaying the limits, and indicate if you want the rule violations noted. See Figure 3-12 for an example of this dialog box.

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point that is plotted on the control chart will remain inside the control limits as a function of the true process mean (see Figure 3-49). It is useful for judging the effectiveness of a control chart in detecting when a process drifts away from the target. The X-axis shows the shift in the average; the Y-axis the probability of not detecting the shift.

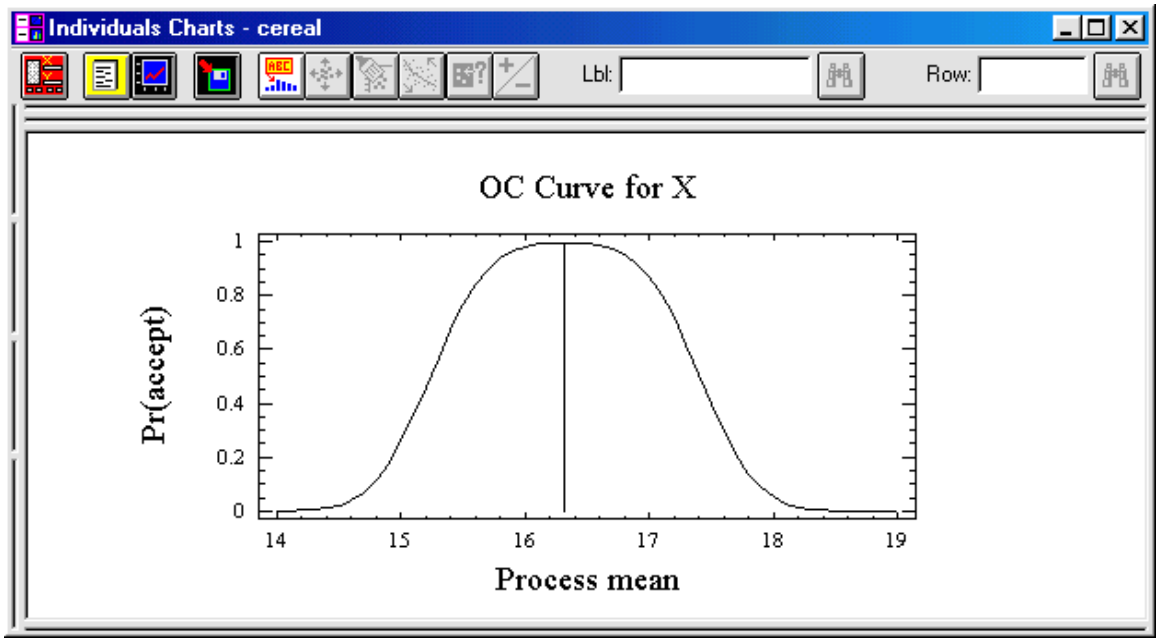

Figure 3-49. OC Curve

ARL Curve

The ARL Curve option creates a plot that shows the average run length (ARL) as a function of the process mean (see Figure 3-50). For example, if the process is actually running at centerline, the chart should generate an out-of-control signal on an approximate average based on the number of samples. If the process moves away from the centerline, the average run length will change. The plot is helpful in choosing an adequate sampling plan to monitor the process.

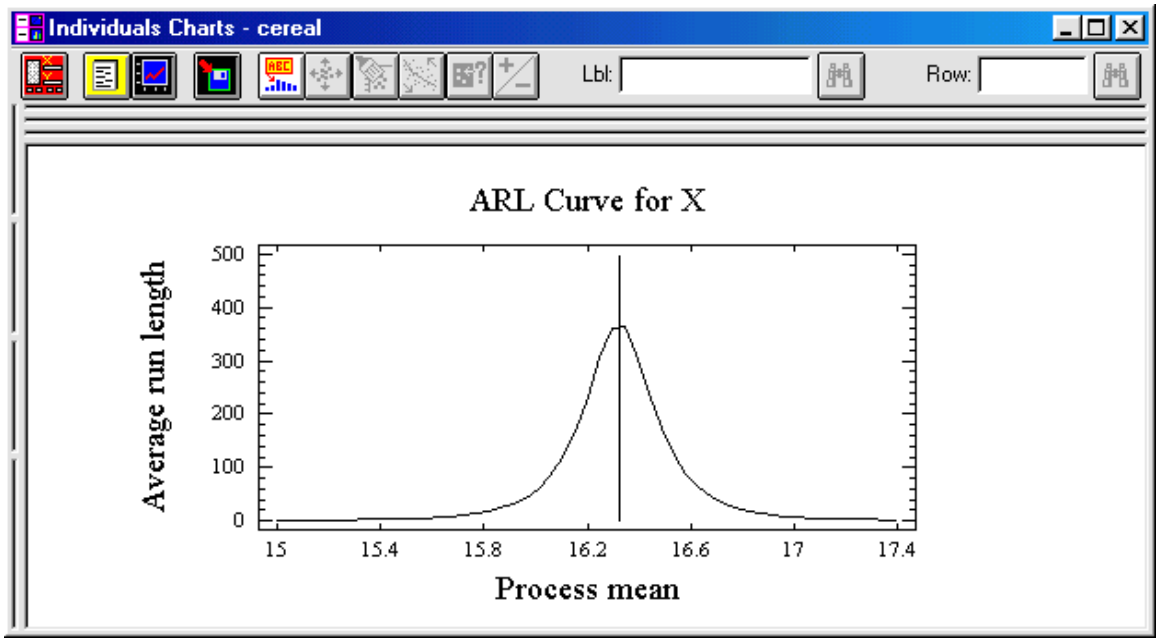

Figure 3-50. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to select the results you want to save. There are six selections: Observations, Moving Ranges, Labels, Process Mean, Process Sigma, and Included Observations.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

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Chapter 4

DETERMINING STATISTICAL CONTROL OF ATTRIBUTE DATA

Manufactured products are routinely inspected by attributes, where each item inspected is classified as either accepted or rejected. In this type of inspection, it is also common to record the number of items that are rejected. If a quality performance comparison is being made, it is also necessary to record the number of items rejected. The ratio of the rejected items to the number of inspected items is known as the *fraction rejected*, which is commonly expressed as a decimal fraction. The decimal fraction is often multiplied by 100 to convert it into a percent rejected (Grant and Leavenworth, 1980).

Usually control charts are thought of in terms of variables, however, they have also been developed for attributes. Attribute data have only two values; for example, conforming/nonconforming, present/absent, or pass/fail such as errors in a word processing document, or the presence of a required label. Grant and Leavenworth (1980), provide other examples such as characteristics that are measurable, but where the results are recorded with a simple yes/no.

Attributes control charts are important because:

- Attribute data already exist in many situations, especially where inspections currently exist. In these cases, no additional data collection is necessary, just the effort of converting the data into control chart format.

- Attribute information is usually quick and inexpensive to obtain in cases where new data must be collected, and it requires no special skills to obtain.

- Data collected for management summaries are usually in attribute form and benefit from control chart analysis, which, because of its ability to distinguish between special and common causes, can be valuable in interpreting management reports.

This chapter contains information about the four attributes control charts: p, np, c, and u. The type of chart you use depends on the way you count the defects.

- Use the p Chart to plot proportions such as the portion of defective items in samples of items. The analysis determines if a process produces an unacceptably high proportion of defective items and is therefore out of control.

- Use the np Chart to plot counts from fixed-size samples such as the number of defective items in samples of items. The analysis produces control charts based on defective items to determine if the process produces an unacceptably high proportion of defective items and therefore it out of control. The np Chart is

appropriate to use when subsizes vary.

- Use the u Chart to plot frequencies that come from interval sampling such as the number of disk failures per hour of computer operation or the total defects in a sample of inspection units. This analysis is more appropriate than the c Chart Analysis when the sample or group sizes are not constant.

- Use the c Chart to plot counts, such as the number of defects per item rather than the number of defects per sample. The chart allows you to construct control limits based on an attribute that is related to a frequency. The program uses a Poisson distribution as the model for the control limits.

With all four analyses you first perform an Initial Study to estimate the control limits to set a standard. Then you perform a Control to Standard and enter either the control limits or the parameters to determine if the process still meets the standard.

With each of the analyses (except the c Chart) you must also indicate whether the data come from equal- or unequal-sized samples. It is also important that the data meet these guidelines:

- for a p Chart, all the values must be between 0 and 1.

- for an np Chart, all the values must be integers between 0 and the size of the subgroup.

- for a u Chart, all the values must be greater than or equal to 0.

- for a c Chart, all the values must be greater than or equal to 0.

Using the p Chart Analysis

A p Chart measures the proportion of defective or nonconforming items in a group of items being inspected. The items could refer to a sample of 25 pieces, taken three times a day; some percentage of production grouped on an hourly or daily basis; or the proportion of on-time deliveries.

A *fraction rejected p* is defined as the ratio of the number of defective (nonconforming) items found in any inspection to the total number of items actually inspected. A fraction rejected is almost always expressed as a decimal fraction.

This chart is the most versatile and widely used attributes control chart. It can be applied to quality characteristics that are considered to be attributes, even though they might also have been measured as variables. If the classification of an individual article is accepted or rejected as the result of an inspection, a p chart can be applied to one or more quality characteristics.

To Access the p Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... ATTRIBUTES CONTROL CHARTS... p CHART... from the Menu bar to display the Analysis dialog box shown in Figure 4-1.

2. Complete the dialog box and click OK to display the Analysis Summary and the p Chart in the Analysis window.

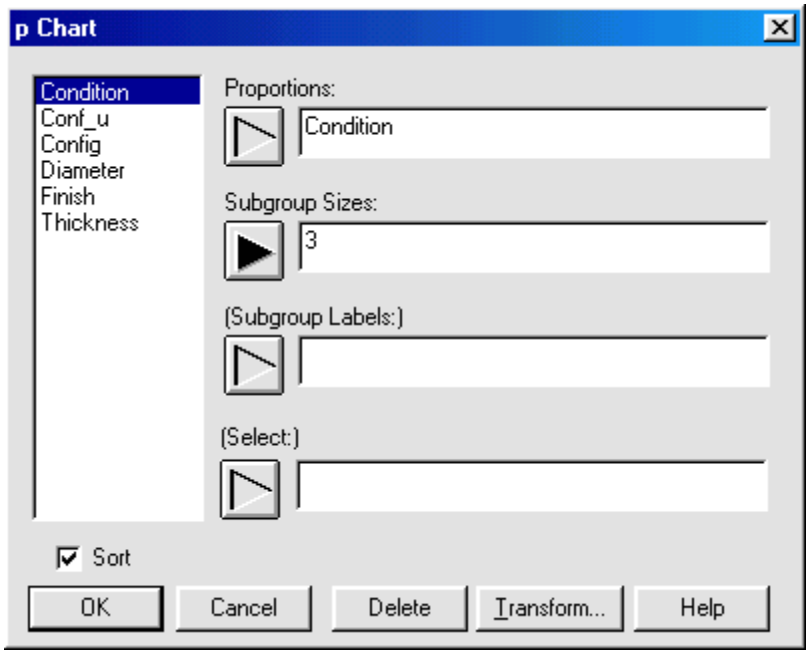

Figure 4-1. p Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 4-2). The program constructs the control charts under the assumption that the data come from a binomial distribution with values for the mean and sigma, which are estimated from the data.

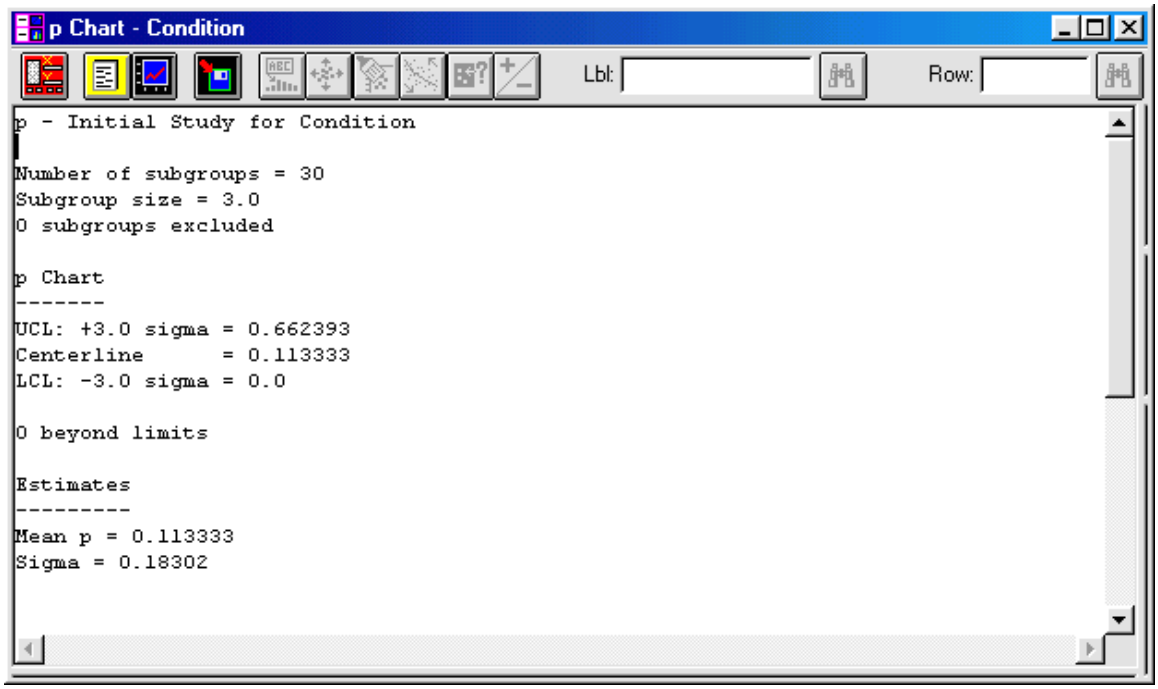

Figure 4-2. Analysis Summary

For this chart, the report displays the values for the upper and lower control limits, the centerline, and the number of subgroups beyond the limits. It also shows the number of subgroups, the subgroup size, and the number of subgroups excluded from the analysis. It provides estimates for the mean and sigma. For a control-to-standard study, the report includes standard statistics.

Use the *p Chart Options* dialog box to indicate if the study will be an initial or a control to standard; to indicate if the data should be normalized to z-scores; and to indicate if the average subgroup size should be used to calculate the control limits (see Figure 4-3). You can also recalculate control limits for specified sets of subgroups. You can enter values for the Upper and Lower Sigma for the p Chart Control Limits.

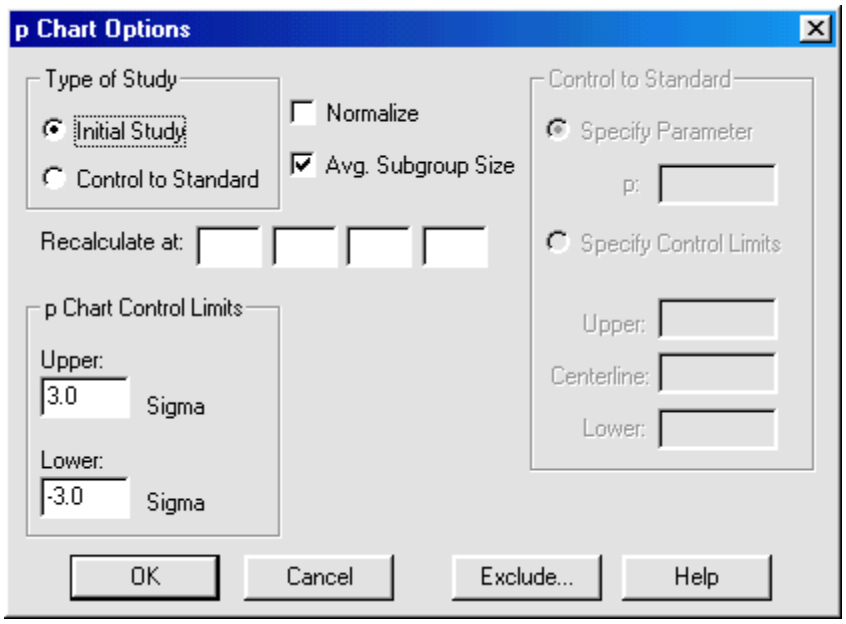

Figure 4-3. p Chart Options Dialog Box

For a Control-to-Standard study, you can choose to either specify the parameter (p) or to specify control limits for the p Chart. For the latter, you enter values for the Upper, Centerline, and Lower limits.

Use the Exclude... command on the dialog box to choose the subgroups you want to exclude from the analysis. When you click the button, the Exclude/Include Options dialog box displays (see Figure 4-4).

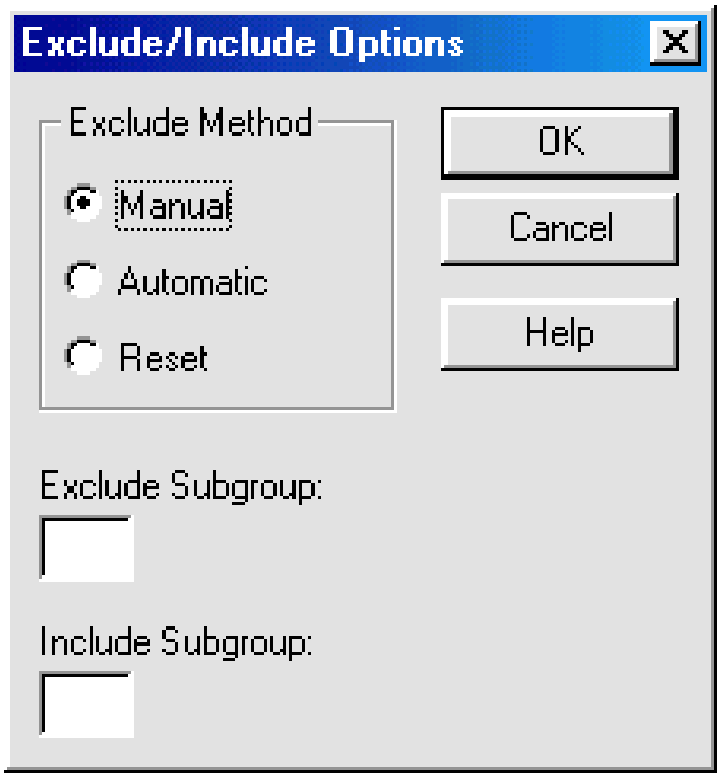

Figure 4-4. Exclude/Include Options Dialog Box

Subgroup Reports

The Subgroup Reports option creates a report based on your selection on the Subgroup Reports Options dialog box (see Figure 4-5). You can create a report of all the subgroups; of the subgroups beyond the control limits; or of the subgroups that were excluded from the analysis. The report lists the subgroup, the subgroup size, and the values for p. Points that are beyond the limits are noted with an asterisk; points that are excluded are noted by an X.

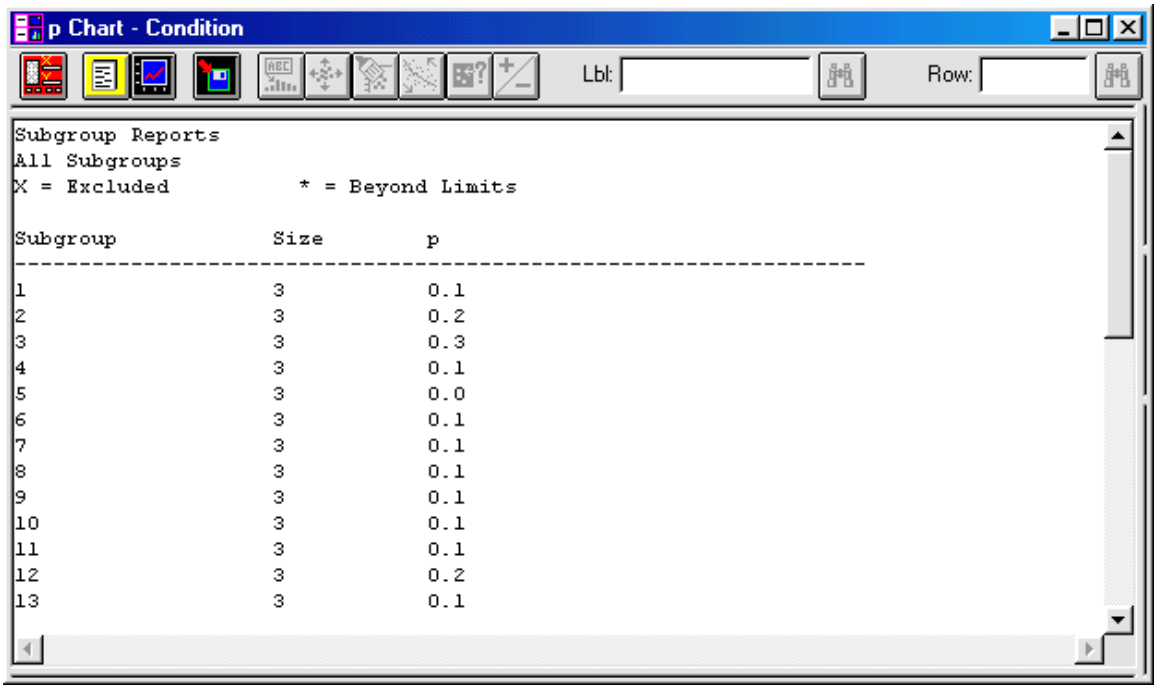

Figure 4-5. Subgroup Reports

Use the *Subgroup Reports Options* dialog box to choose the type of reports that will be included: All Subgroups, Subgroups Beyond Limits, or Excluded Subgroups (see Figure 4-6).

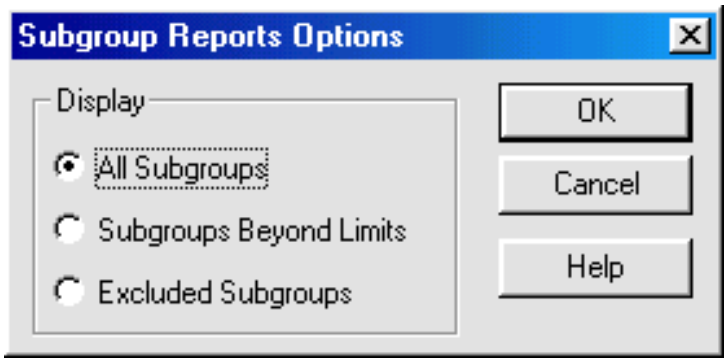

Figure 4-6. Subgroup Reports Options Dialog Box

Runs Tests

The Runs Tests option searches for and identifies any unusual patterns in the data (see Figure 4-7). The tests are helpful in detecting processes that are slowly drifting away from the target (even though no points may fall outside the control limits). The report displays the subgroup at which the unusual pattern was detected as well as the rule that was violated. A nonrandom pattern indicates that a process is out of control.

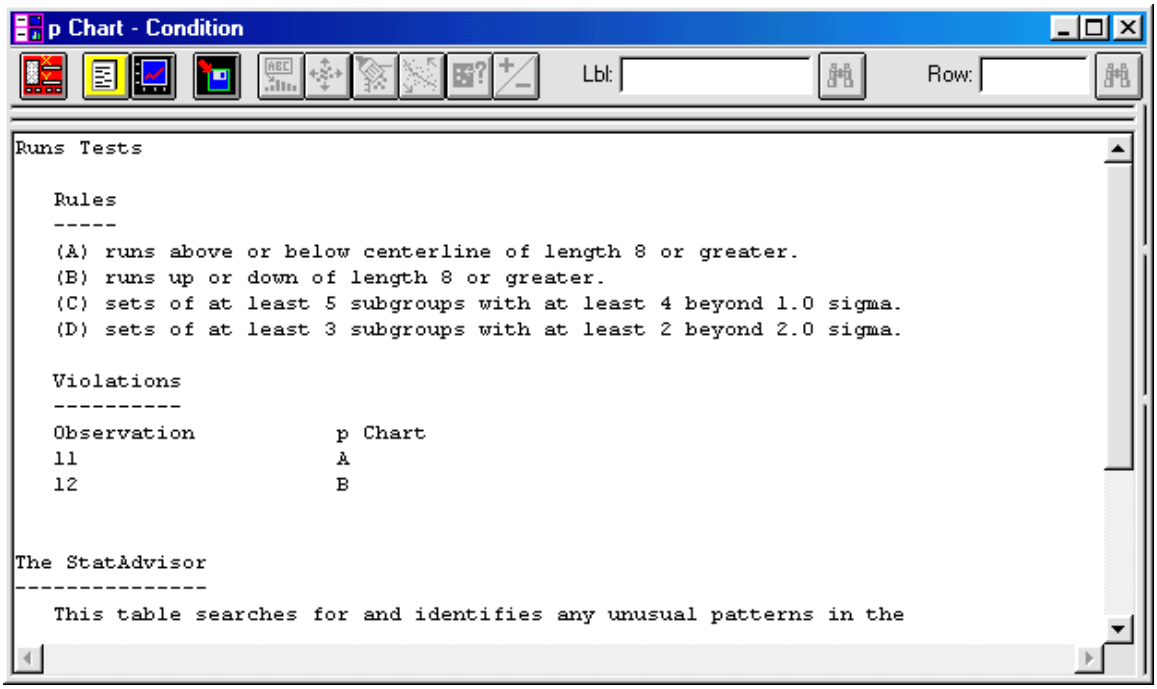

Figure 4-7. Runs Tests

Use the *Runs Tests Options* dialog box to indicate the guidelines for the tests and the violation rules (see Figure 4-8).

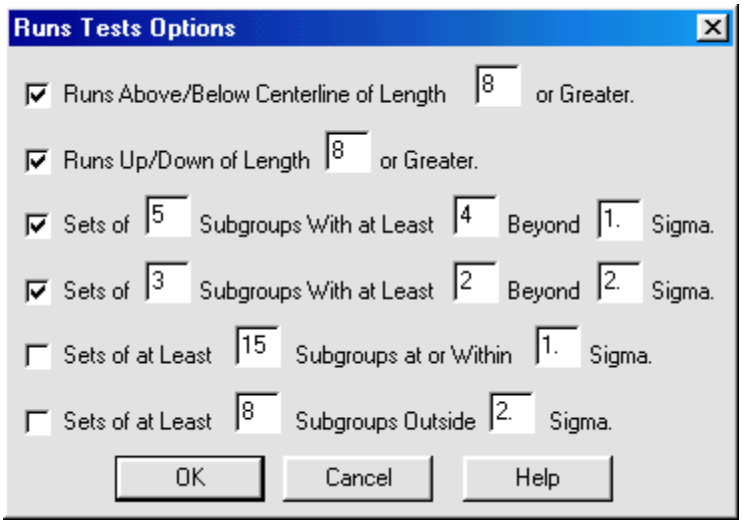

Figure 4-8. Runs Tests Options Dialog Box

Graphical Options

p Chart

The p Chart option creates a plot of the proportions for each of the subgroups. A process is considered out of control if points are shown outside the control limits, or if

points are shown within the control limits, but arranged in a nonrandom sequence (see Figure 4-9).

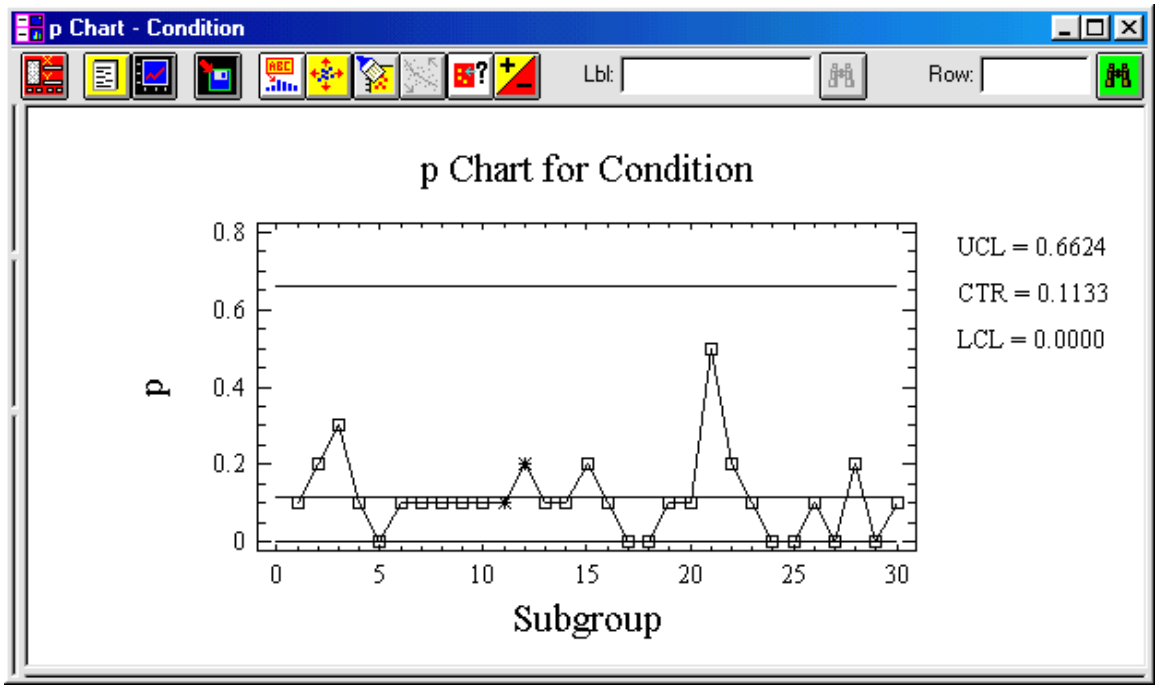

Figure 4-9. p Chart

Use the *Control Chart Options* dialog box to indicate if outer and inner warning limits should be calculated, and if so, to enter a value for sigma (see Figure 4-10). You also indicate if the moving average and exponentially weighted moving average should be calculated, and if so, to enter values for the order and lambda, respectively. You also enter a value for the number of decimal places to be used for displaying the limits, and indicate if you want the rule violations noted.

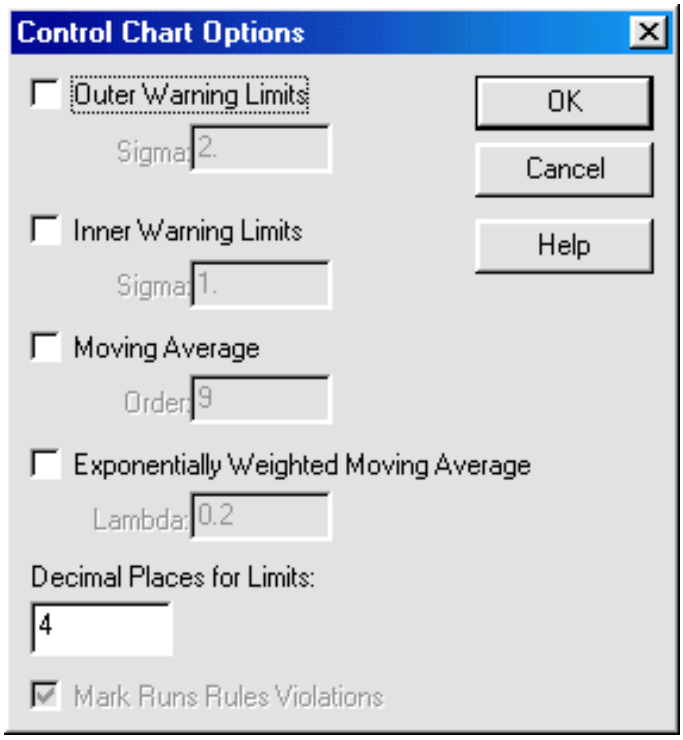

Figure 4-10. Control Chart Options Dialog Box

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point that is plotted on the control chart will remain inside the control limits as a function of the true process proportion (see Figure 4-11). It is useful for judging the effectiveness of a control chart in detecting when a process drifts away from the target. The X-axis shows the shift in the proportion; the Y-axis the probability of not detecting the shift.

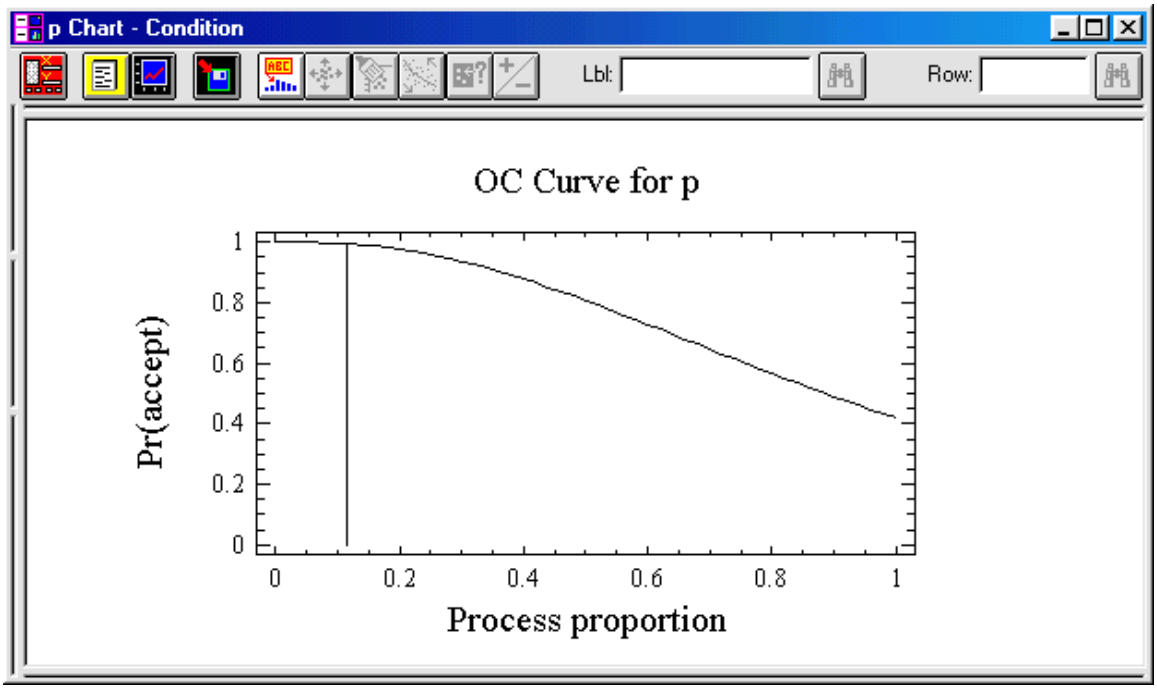

Figure 4-11. OC Curve

ARL Curve

The ARL Curve option creates a plot that shows the average run length (ARL) as a function of the process proportion (see Figure 4-12). For example, if the process is actually running at Centerline, the chart should generate an out-of-control signal on an approximate average based on the number of samples. If the process moves away from the centerline, the average run length will change. The plot is helpful in choosing an adequate sampling plan to monitor the process.

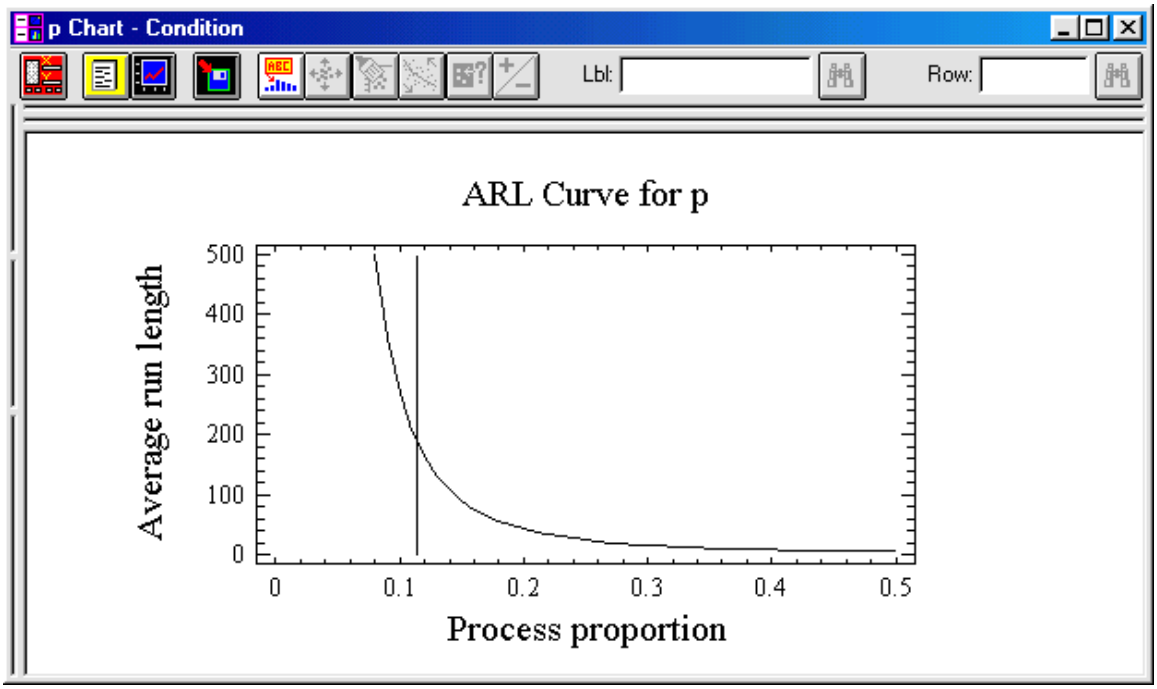

Figure 4-12. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to select the results you want to save. There are five selections: Proportions, Sizes, Labels, Mean p, and Sigma.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the np Chart Analysis

An np Chart is appropriate for use whenever the subgroup size varies and the control chart must show the actual number of rejected items rather than the fraction or proportion rejected. If the actual numbers of rejects were to be plotted, the central line on the chart as well as the control limits would have to be changed each time there was a change in the size of the subgroup. If the subgroup size remains constant, a chart for actual numbers can be used.

To Access the np Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... ATTRIBUTES CONTROL CHARTS... np CHART... from the Menu bar to display the Analysis dialog box shown in Figure 4-13.

2. Complete the dialog box and click OK to display the Analysis Summary and the np Chart in the Analysis window.

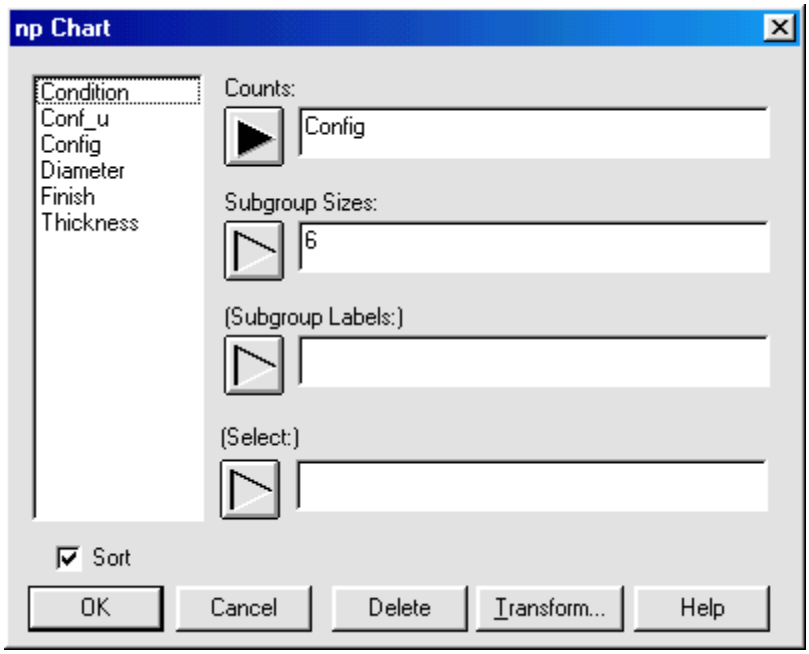

Figure 4-13. np Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 4-14). The program constructs the control charts under the assumption that the data come from a binomial distribution with values for the mean and sigma, which are estimated from the data.

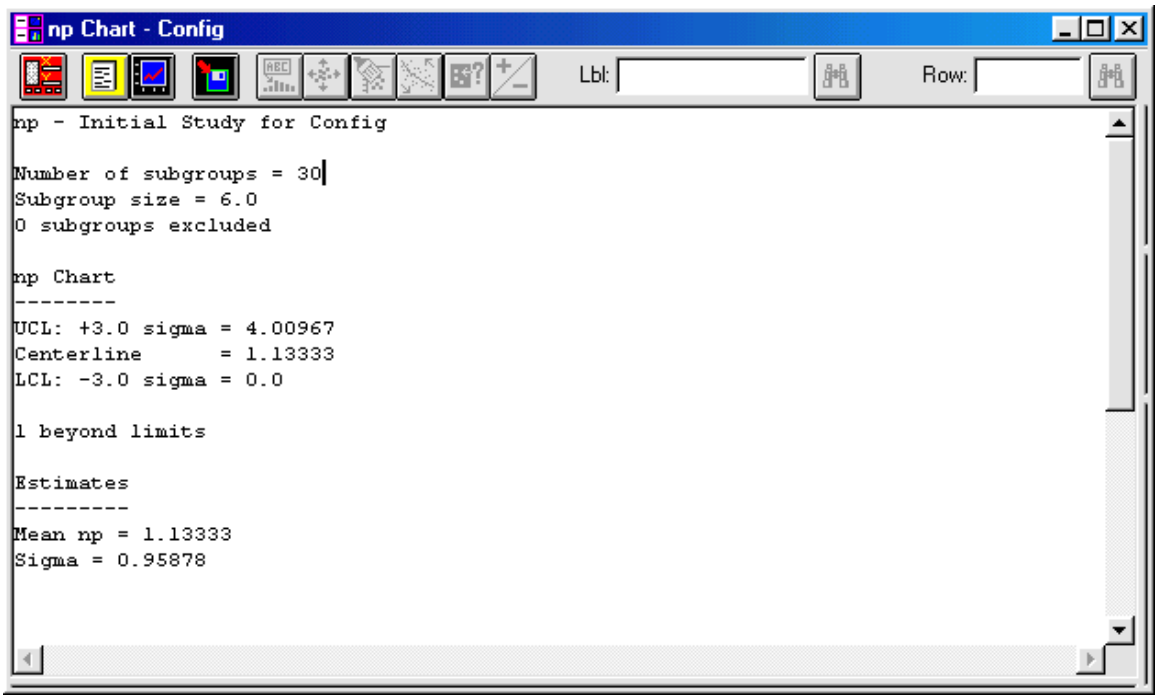

Figure 4-14. Analysis Summary

For this chart, the report displays the values for the upper and lower control limits, the centerline, and the number of subgroups beyond the limits. It also shows the number of subgroups, the subgroup size, and the number of subgroups excluded from the analysis. It provides estimates for the mean and sigma. For a control-to-standard study, the report includes standard statistics.

Use the *np Chart Options* dialog box to indicate if the study will be an initial or a control to standard; to indicate if the data should be normalized to z-scores; and to indicate if the average subgroup size should be used to calculate the control limits. You can also recalculate control limits for specified sets of subgroups. You can enter values for the Upper and Lower Sigma for the np Chart Control Limits (see Figure 4-15).

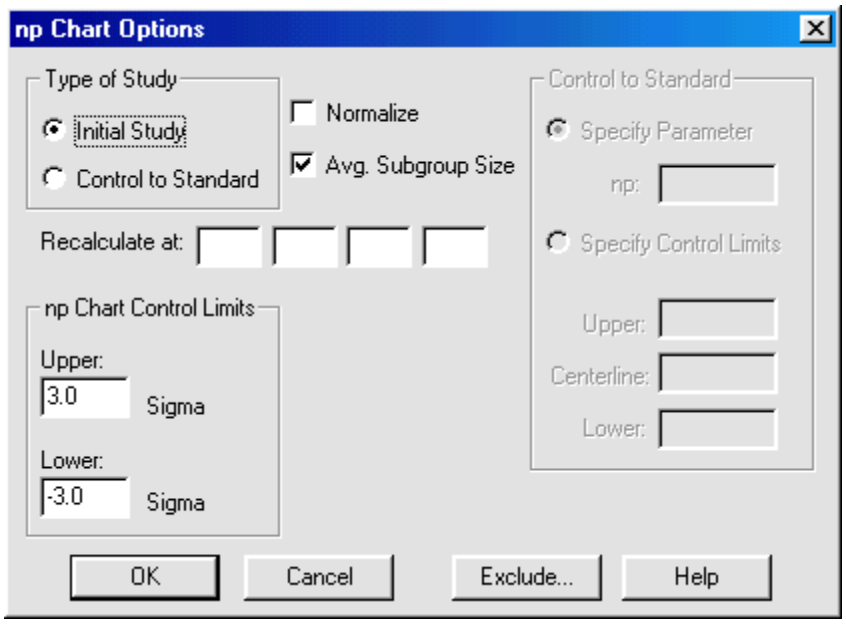

Figure 4-15. np Control Chart Options Dialog Box

For a Control-to-Standard study, you can choose to either specify the parameter (np) or to specify control limits for the np Chart. For the latter you can enter values for the Upper, Centerline, and Lower limits.

Use the Exclude... command on the dialog box to choose the subgroups you want to exclude from the analysis. When you click the button, the Exclude/Include Options dialog box displays. See Figure 4-4 for an example of this dialog box.

Subgroup Reports

The Subgroup Reports option creates a report based on your selection on the Subgroup Reports Options dialog box (see Figure 4-16). You can create a report of all the subgroups; of the subgroups beyond the control limits; or of the subgroups that were excluded from the analysis. The report lists the subgroup, the subgroup size, and the values for np. Points that are beyond the limits are noted with an asterisk; points that are excluded are noted by an X.

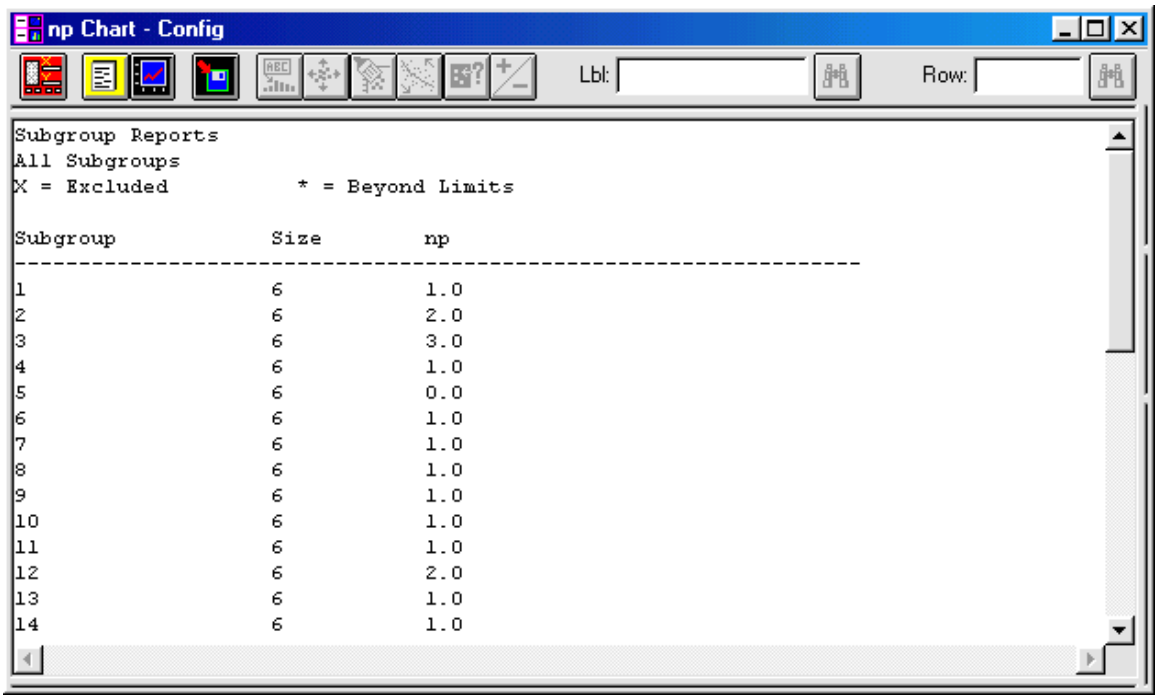

Figure 4-16. Subgroup Reports

Use the *Subgroup Reports Options* dialog box to choose the type of reports that will be included: All Subgroups, Subgroups Beyond Limits, or Excluded Subgroups (see Figure 4-17).

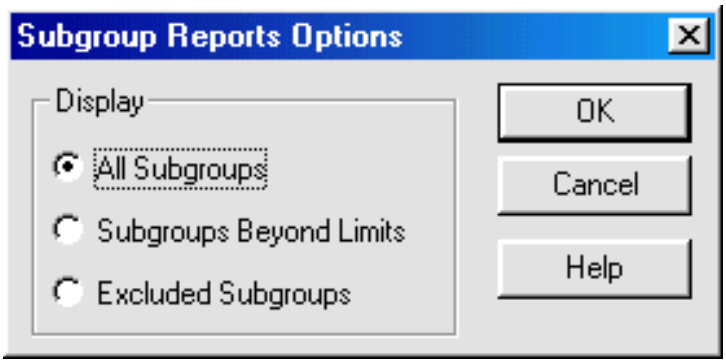

Figure 4-17. Subgroup Reports Options Dialog Box

Runs Tests

The Runs Tests option searches for and identifies any unusual patterns in the data. The tests are helpful in detecting processes that are slowly drifting away from the target (even though no points may fall outside the control limits) (see Figure 4-18). The report displays the subgroup at which the unusual pattern was detected as well as the rule that was violated. A nonrandom pattern indicates that a process is out of control.

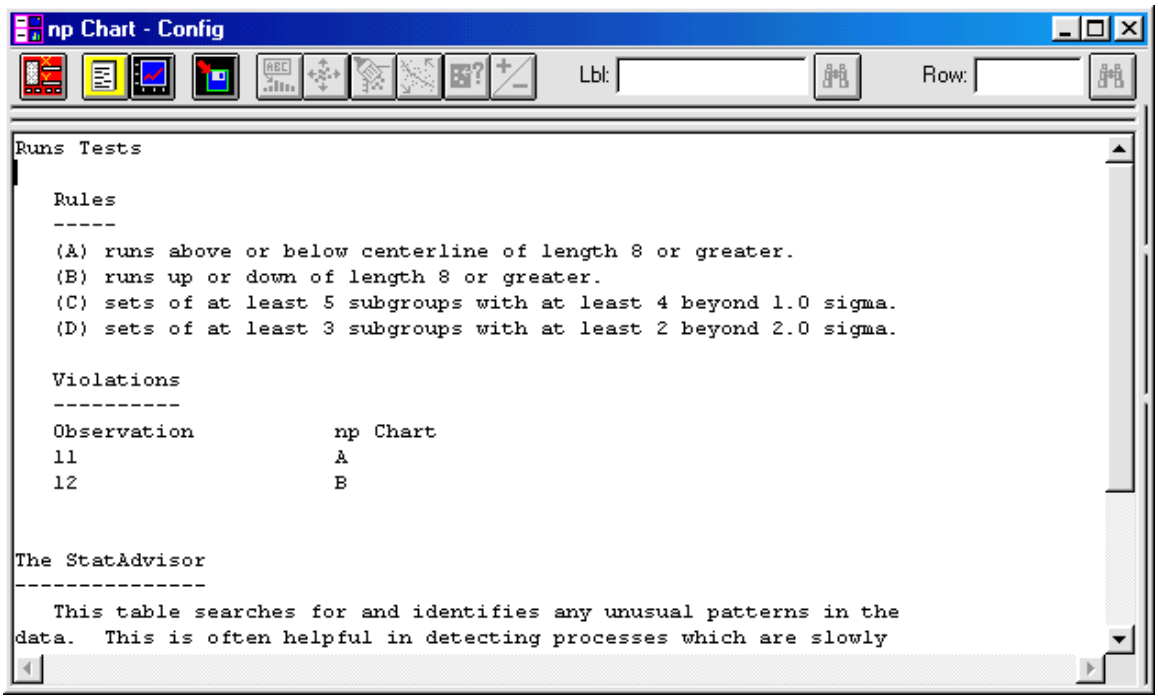

Figure 4-18. Runs Tests

Use the *Runs Tests Options* dialog box to indicate the guidelines for the tests and the violation rules (see Figure 4-19).

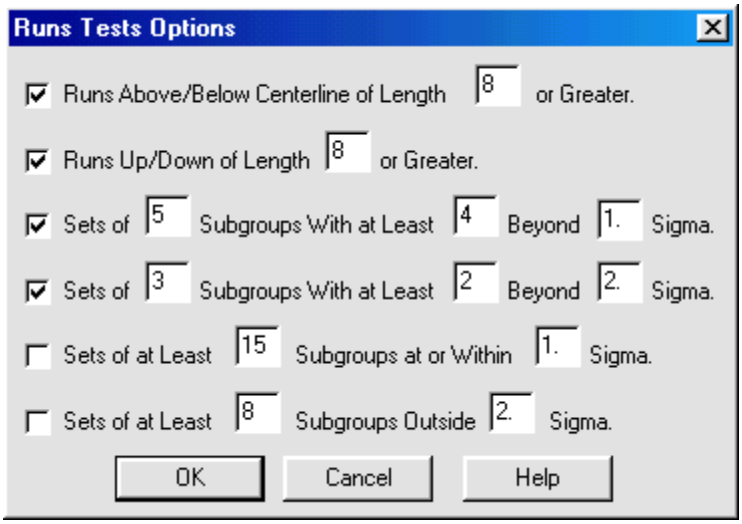

Figure 4-19. Runs Tests Options Dialog Box

Graphical Options

np Chart

The np Chart option creates a plot of the proportions for each of the subgroups (see Figure 4-20). A process is considered out of control if points are shown outside the

control limits, or if points are shown within the control limits, but arranged in a nonrandom sequence.

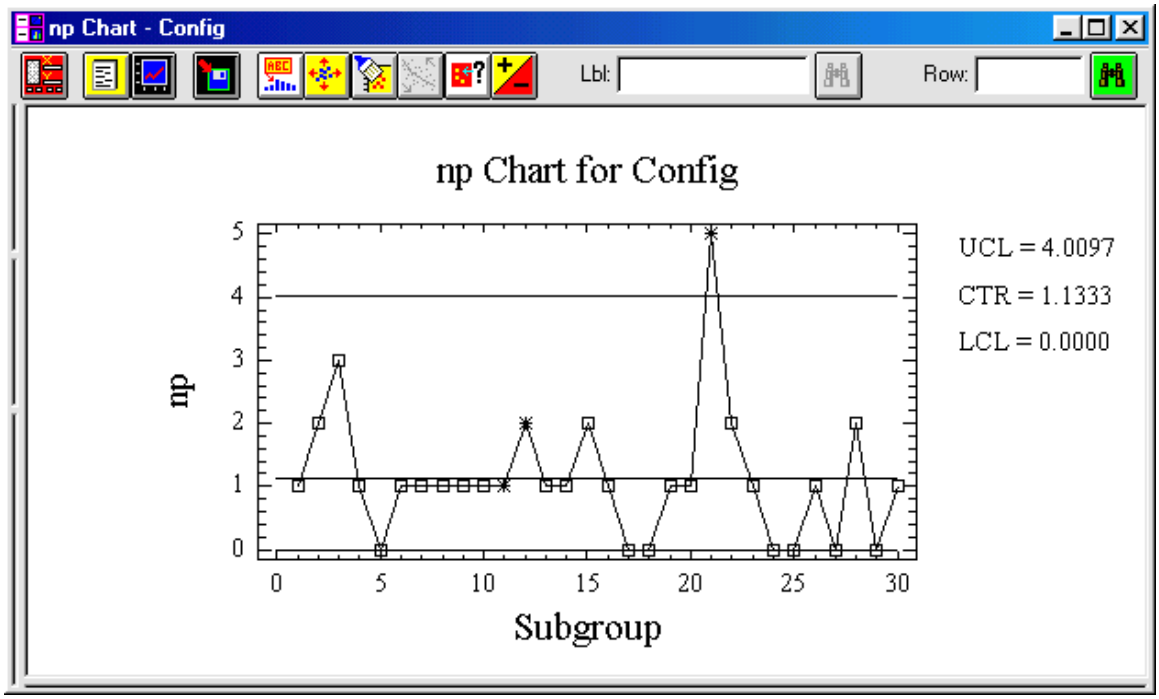

Figure 4-20. np Chart

Use the *Control Chart Options* dialog box to indicate if outer and inner warning limits should be calculated, and if so, to enter a value for sigma. You also indicate if the moving average and exponentially weighted moving average should be calculated, and if so, to enter values for the order and lambda, respectively. You also enter a value for the number of decimal places for displaying the limits, and indicate if you want the rule violations noted. See Figure 4-10 for an example of this dialog box.

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point that is plotted on the control chart will remain inside the control limits as a function of the true process mean count. It is useful for judging the effectiveness of a control chart in detecting when a process drifts away from the target (see Figure 4-21). The X-axis shows the shift in the average count; the Y-axis the probability of not detecting the shift.

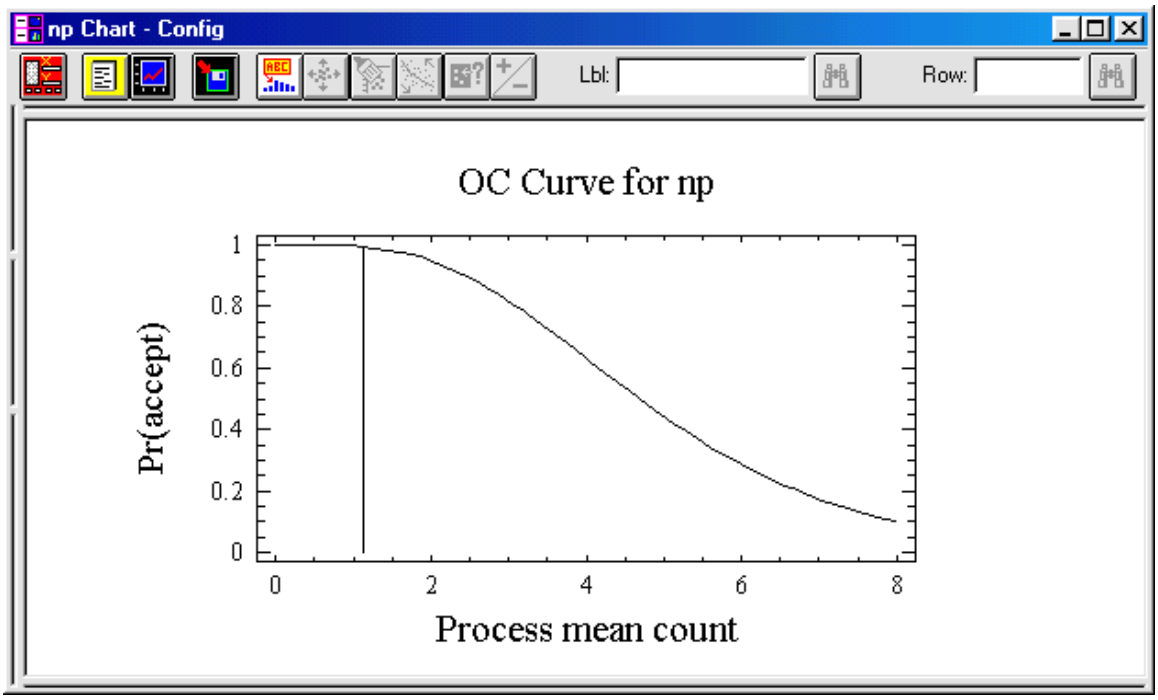

Figure 4-21. OC Curve

ARL Curve

The ARL Curve option creates a plot that shows the average run length (ARL) as a function of the process proportion (see Figure 4-22). For example, if the process is actually running at Centerline, the chart should generate an out-of-control signal on an approximate average based on the number of samples. If the process moves away from the centerline, the average run length will change. The plot is helpful in choosing an adequate sampling plan to monitor the process.

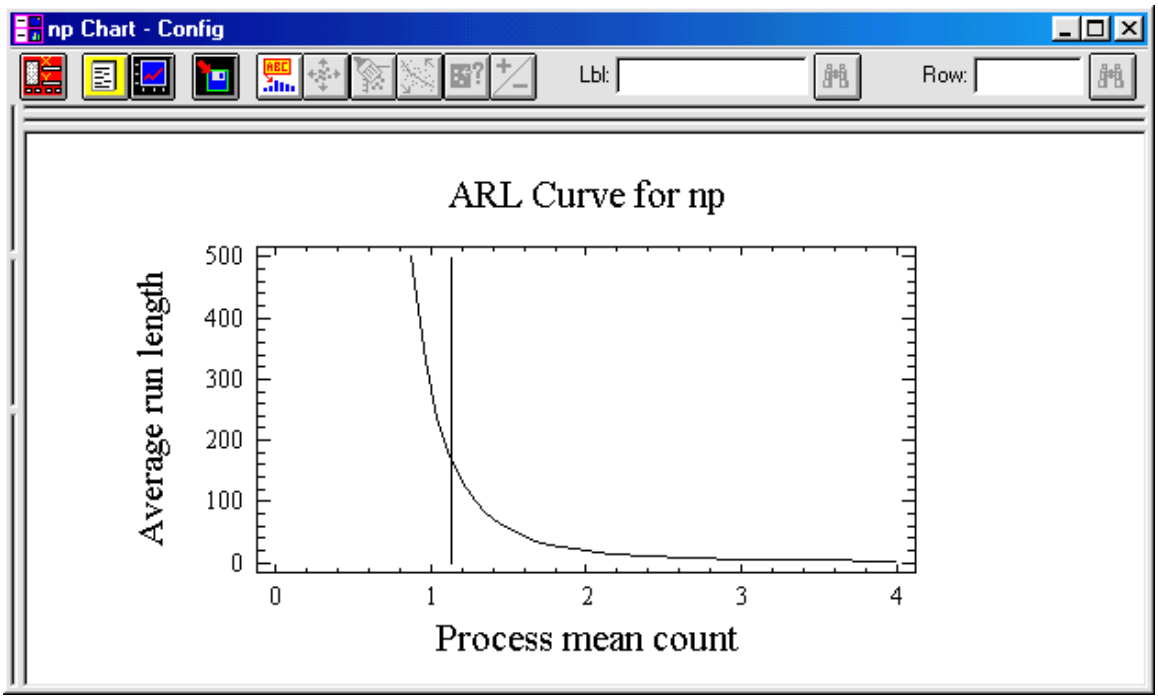

Figure 4-22. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to select the results you want to save. There are five selections: np s, Sizes, Labels, Mean np, and Sigma.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the u Chart Analysis

A u Chart measures the number of nonconformities (defects) per inspection reporting unit in subgroups that can have varying sample sizes. It is similar to a c chart except that the number of nonconformities is expressed on a per unit basis. Both u and c charts are appropriate for the same type of information; however, a u Chart can be used if the sample includes more than one unit and it must be used if the sample size varies from period to period.

To Access the u Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... ATTRIBUTES CONTROL CHARTS... u CHART... from the Menu bar to display the Analysis dialog box shown in Figure 4-23.

2. Complete the dialog box and click OK to display the Analysis Summary and the c Chart in the Analysis window.

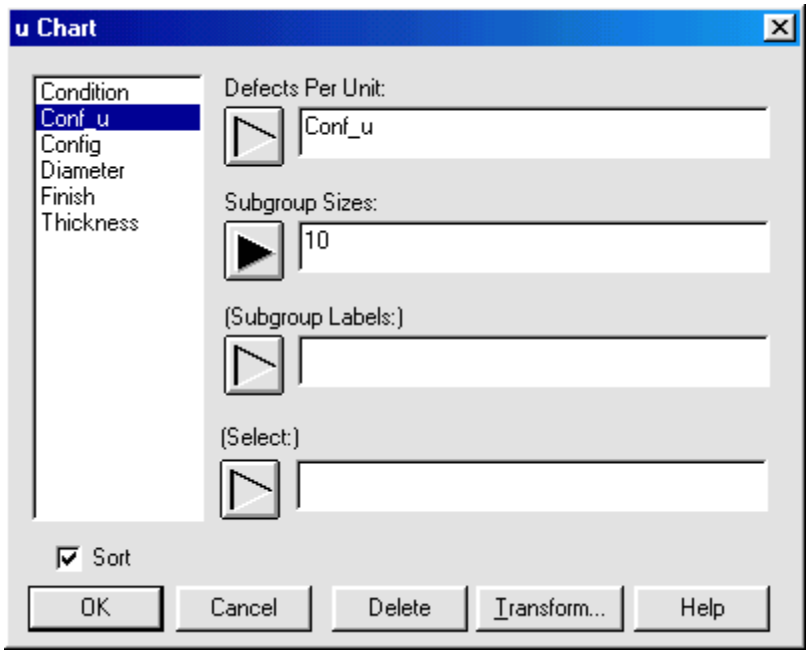

Figure 4-23. u Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 4-24). The program constructs the control charts under the assumption that the data come from a Poisson distribution with values for the mean u and sigma, which are estimated from the data.

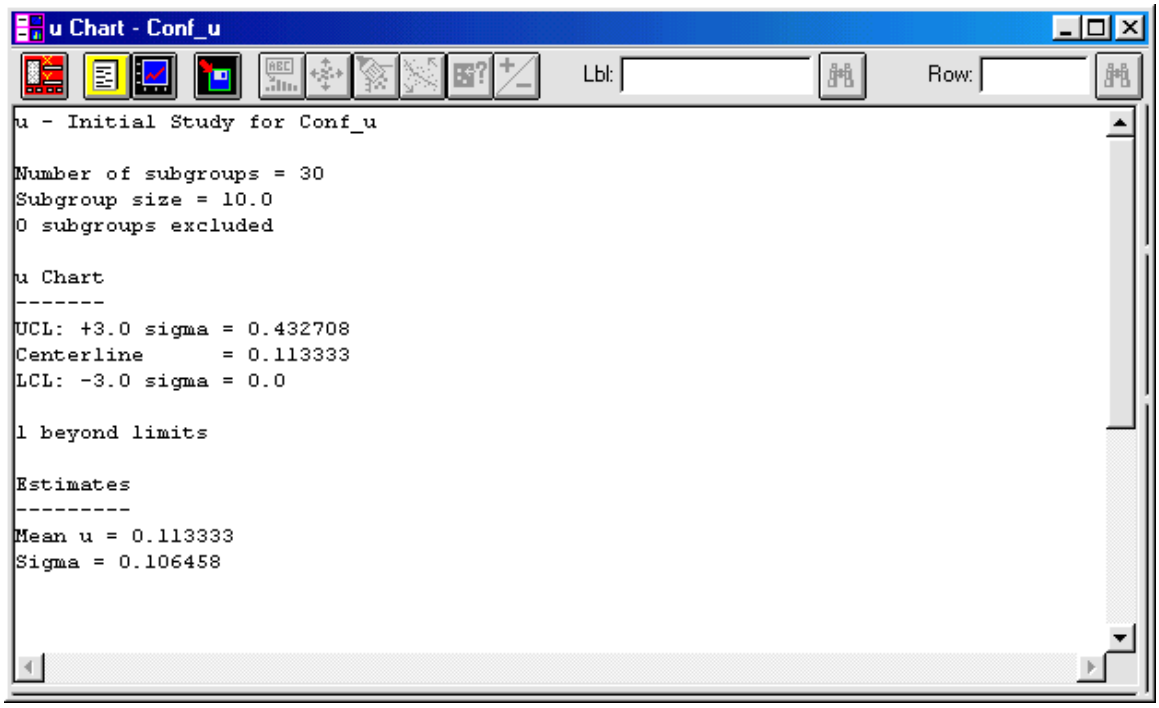

Figure 4-24. Analysis Summary

For this chart, the report displays the values for the upper and lower control limits, the centerline, and the number of subgroups beyond the limits. It also shows the number of subgroups, the subgroup size, and the number of subgroups excluded from the study. It provides estimates for the mean u and sigma. For a control-to-standard study, the report includes standard statistics.

Use the *u Chart Options* dialog box to indicate if the study will be an initial or a control to standard; to indicate if the data should be normalized to z-scores; and to indicate if the average subgroup size should be used to calculate the control limits. You can also recalculate control limits for specified sets of subgroups. You can enter values for the Upper and Lower Sigma for the u Chart Control Limits (see Figure 4-25).

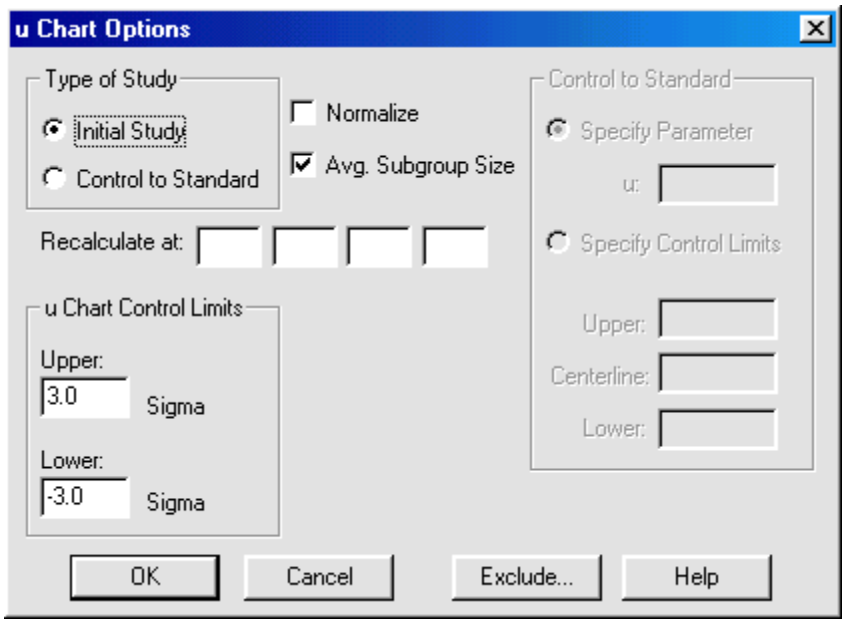

Figure 4-25. u Chart Options Dialog Box

For a Control-to-Standard study, you can choose to either specify the parameter (u) or to specify control limits for the u Chart. For this you can enter values for the Upper, Centerline, and Lower limits.

Use the Exclude... command on the dialog box to choose the subgroups you want to exclude from the analysis. When you click the button, the Exclude/Include Options dialog box displays. See Figure 4-4 for an example of this dialog box.

Subgroup Reports

The Subgroup Reports option creates a report based on your selection on the Subgroup Reports Options dialog box. You can create a report of all the subgroups, of the subgroups beyond the control limits; or of the subgroups that were excluded from the analysis. The report lists the subgroup, the subgroup size, and the values for u (see Figure 4-26). Points that are beyond the limits are noted with an asterisk; points that are excluded are noted by an X.

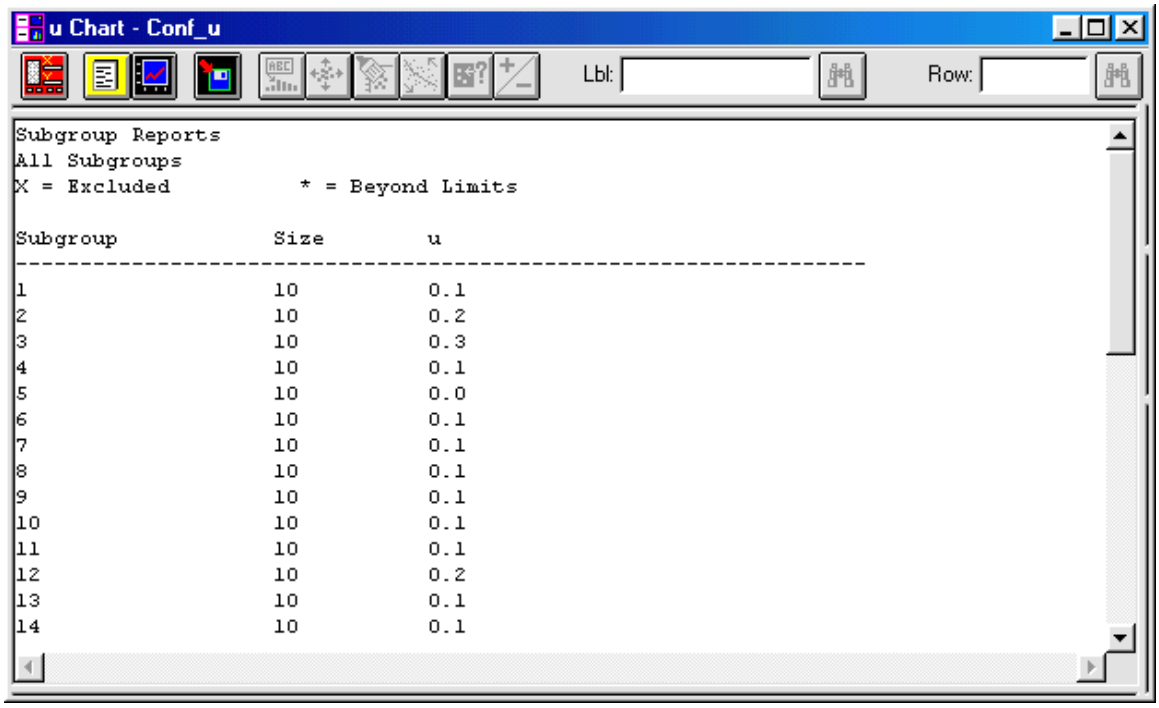

Figure 4-26. Subgroup Reports

Use the *Subgroups Report Options* dialog box to choose the type of reports that will be included: All Subgroups, Subgroups Beyond Limits, or Excluded Subgroups. See Figure 4-6 for an example of this dialog box.

Runs Tests

The Runs Tests option searches for and identifies any unusual patterns in the data. The tests are helpful in detecting processes that are slowly drifting away from the target (even though no points may fall outside the control limits) (see Figure 4-27). The report displays the subgroup at which the unusual pattern was detected as well as the rule that was violated. A nonrandom pattern indicates that a process is out of control.

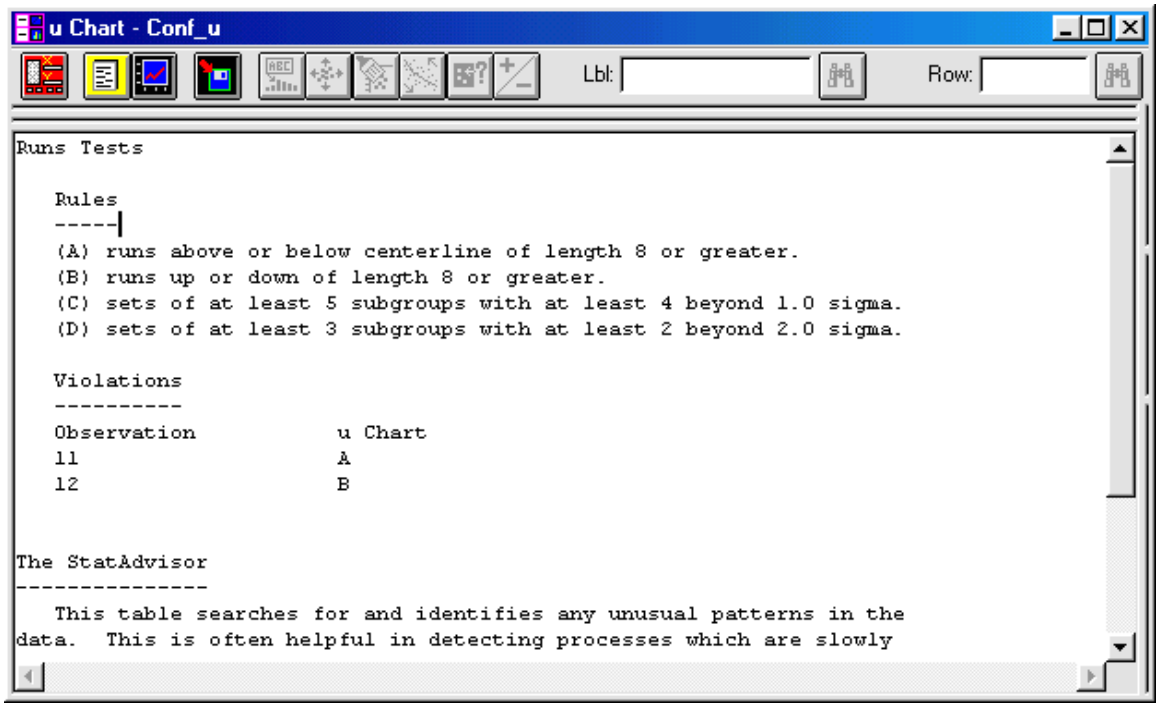

Figure 4-27. Runs Tests

Use the *Runs Tests Options* dialog box to indicate the guidelines for the tests and the violation rules. See Figure 4-8 for an example of this dialog box.

Graphical Options

u Chart

The u Chart option creates a plot of the nonconformities for each of the observations (see Figure 4-28). A process is considered out of control if points are shown outside the control limits, or if points are shown within the control limits, but arranged in a nonrandom sequence.

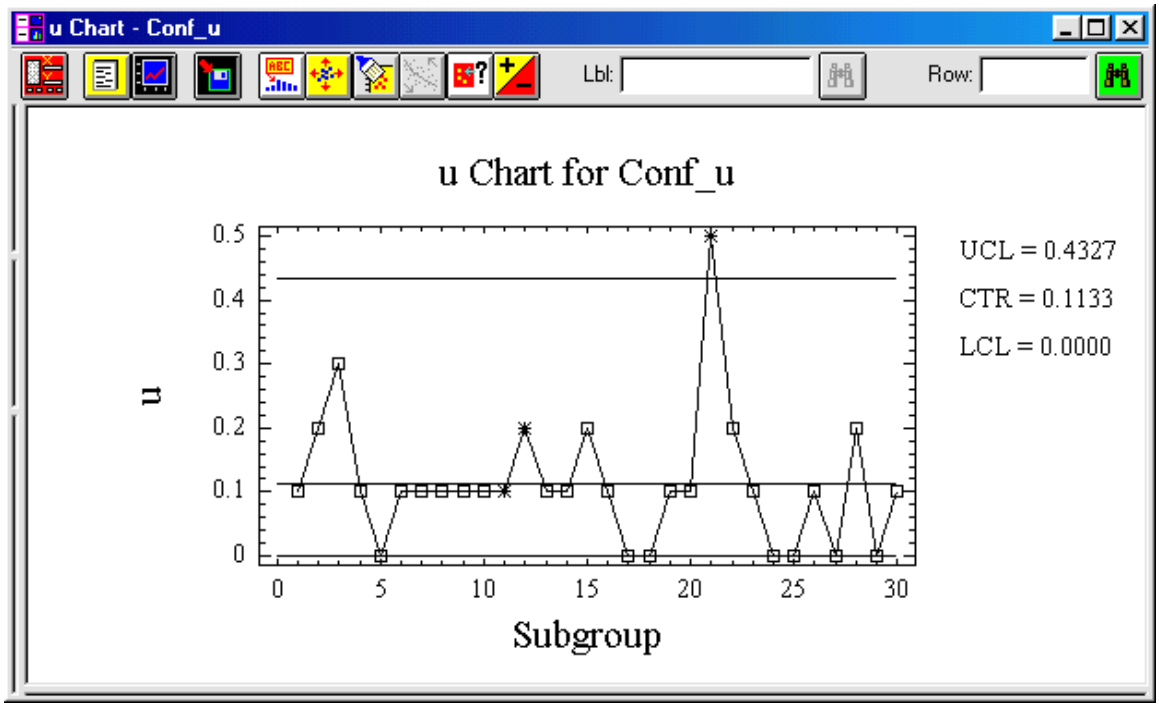

Figure 4-28. u Chart

Use the *Control Chart Options* dialog box to indicate if outer and inner warning limits should be calculated, and if so, to enter a value for sigma. You also indicate if the moving average and exponentially weighted moving average should be calculated, and if so, to enter values for the order and lambda, respectively. You also enter a value for the number of decimal places for displaying the limits, and indicate if you want the rule violations noted. See Figure 4-10 for an example of this dialog box.

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point that is plotted on the control chart will remain inside the control limits as a function of the true process mean count. It is useful for judging the effectiveness of a control chart in detecting when a process drifts away from the target (see Figure 4-29). The X-axis shows the shift in the process frequency; the Y-axis the probability of not detecting the shift.

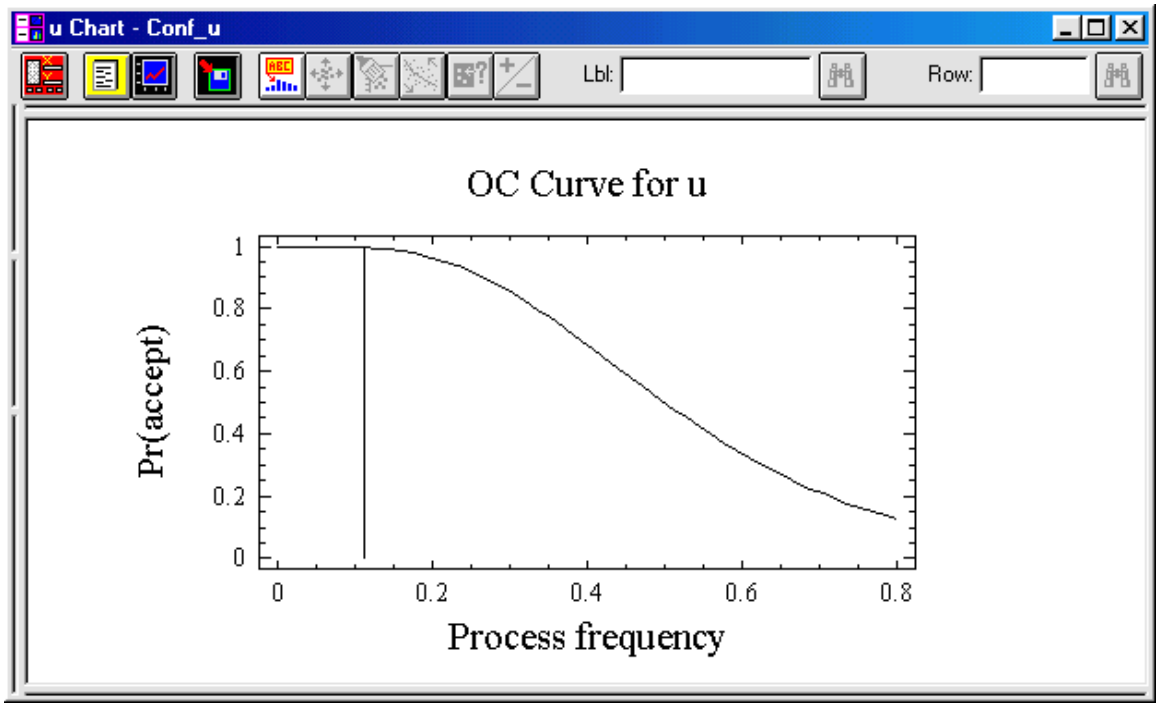

Figure 4-29. OC Curve

ARL Curve

The ARL Curve option creates a plot that shows the average run length (ARL) as a function of the process frequency (see Figure 4-30). For example, if the process is actually running at Centerline, the chart should generate an out-of-control signal on an approximate average based on the number of samples. If the process moves away from the centerline, the average run length will change. The plot is helpful in choosing an adequate sampling plan to monitor the process.

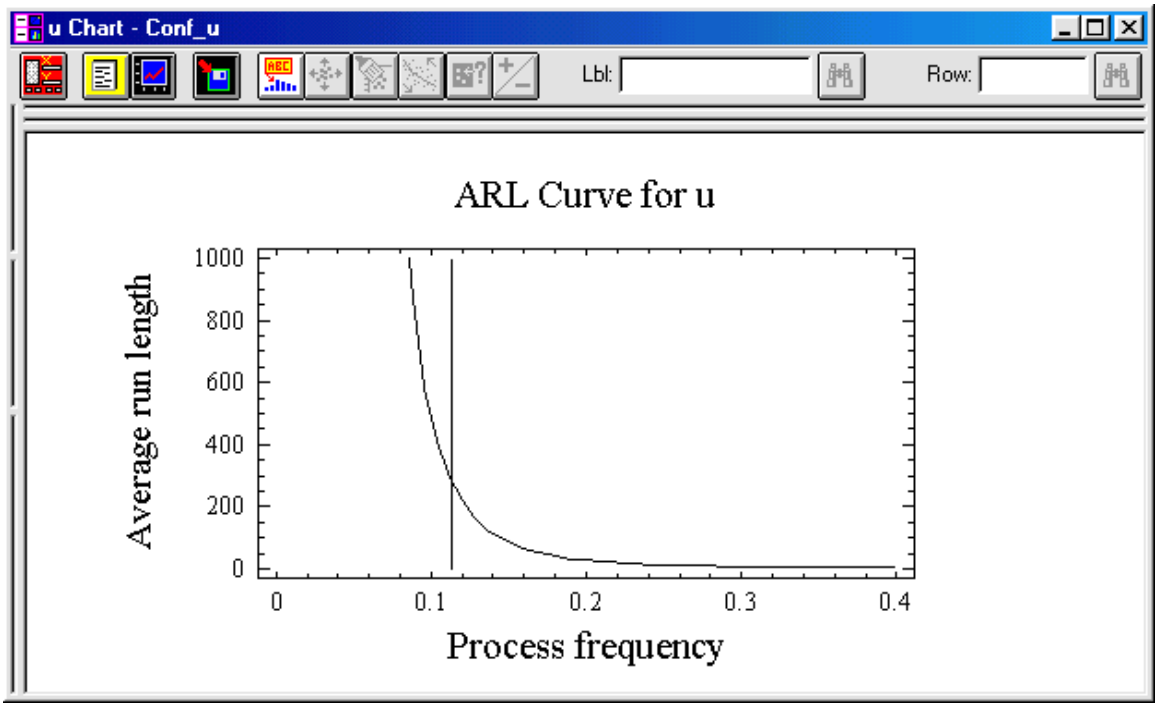

Figure 4-30. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to select the results you want to save. There are five selections: u s, Sizes, Labels, Mean u, and Sigma.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the c Chart Analysis

A c Chart has a much more restricted area of usefulness than other control charts in that it is mostly used for nonconformities. However, in certain manufacturing and inspection situations the chart is definitely needed. It must first be determined if its use is appropriate from the viewpoint of statistical theory, then it is necessary to determine if it is really the best technique to use for the intended purpose.

A *nonconforming* or *defective* item is one that fails in some way to conform to one or more specifications. Each time the item fails to conform is a *nonconformity*, therefore, every nonconforming item contains one or more nonconformities. When it is necessary to make a total count of the nonconformities in each item, or in each

group of an equal number of similar items, it may be reasonable to use a technique based on a Poisson distribution, which means using either a c Chart or a u Chart.

To Access the c Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... ATTRIBUTES CONTROL CHARTS... c CHART... from the Menu bar to display the Analysis dialog box shown in Figure 4-31.

2. Complete the dialog box and click OK to display the Analysis Summary and the c Chart in the Analysis window.

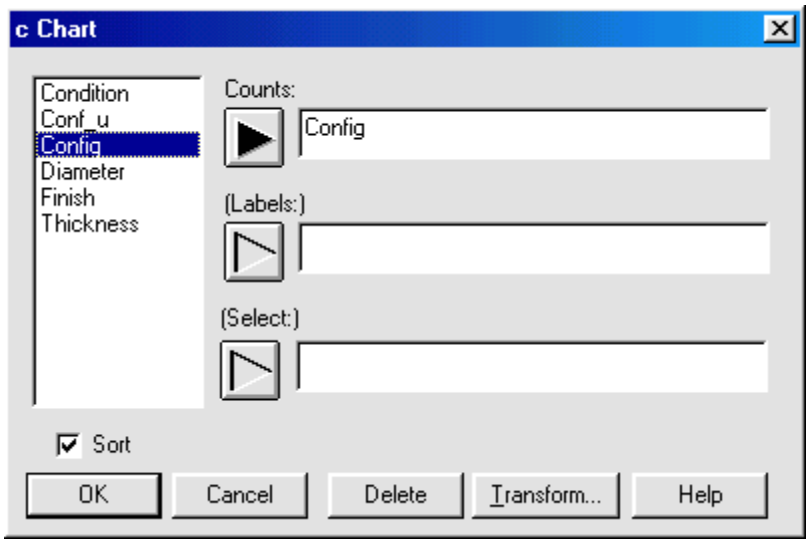

Figure 4-31. c Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 4-32). The program constructs the control charts under the assumption that the data come from a Poisson distribution with values for the mean c and sigma, which are estimated from the data.

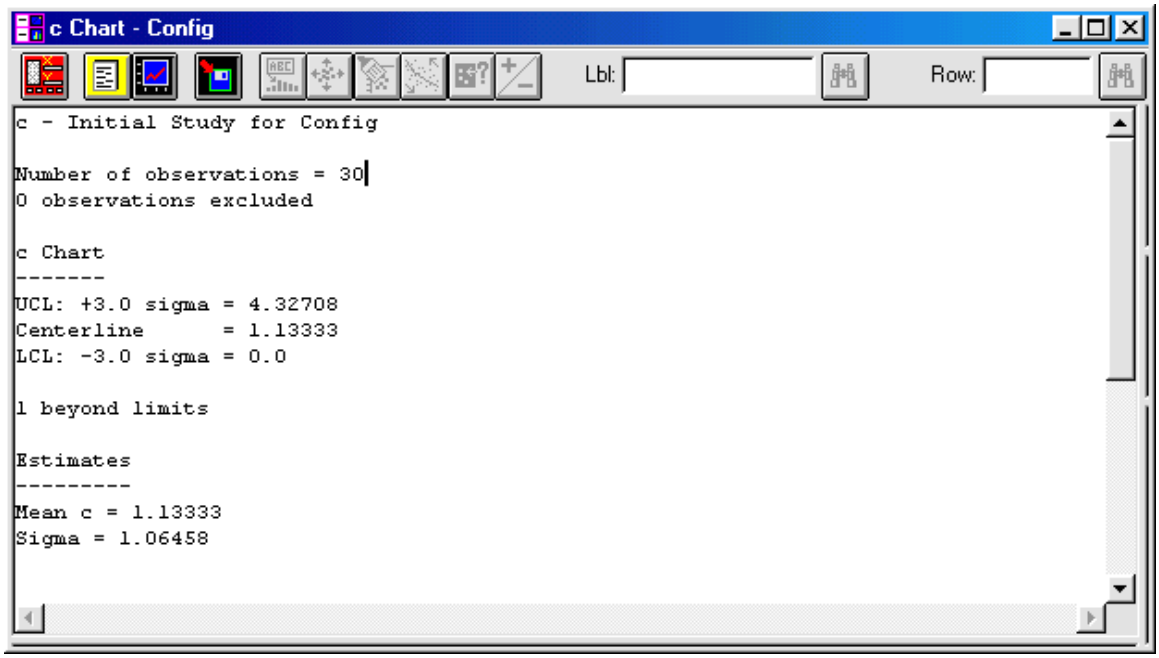

Figure 4-32. Analysis Summary

For this chart, the report displays the values for the upper and lower control limits, the centerline, and the number of observations beyond the limits. It also shows the number of observations, and the number of observations excluded from the study. It provides estimates for the mean c and sigma. For a control-to-standard study, the report includes standard statistics.

Use the *c Chart Options* dialog box to indicate if the study will be an initial or a control to standard; and to indicate if the data should be normalized to z-scores (see Figure 4-33). You can also enter calculate control limits for specified sets of subgroups. You can enter values for the Upper and Lower Sigma for the c Chart Control Limits.

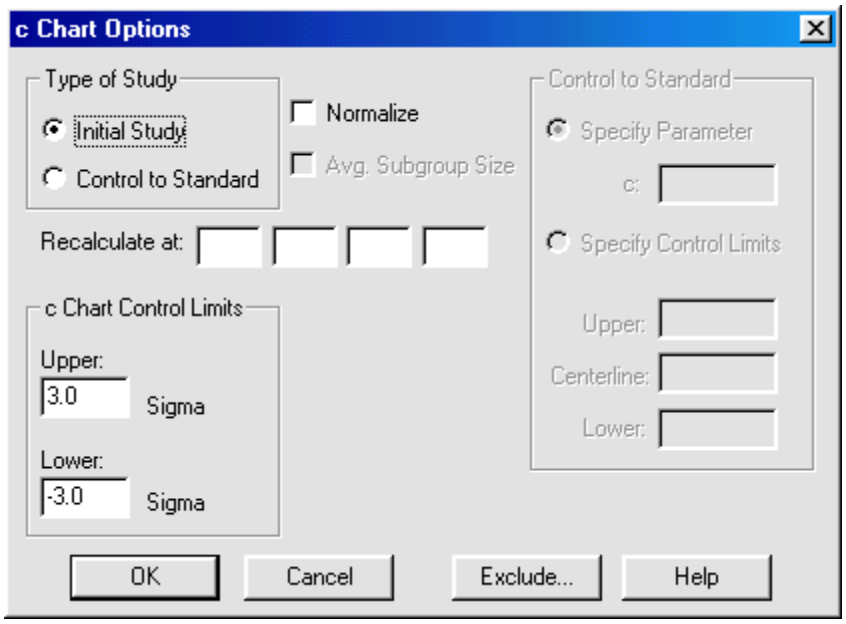

Figure 4-33. c Chart Options Dialog Box

For a Control-to-Standard study, you can choose to either specify the parameter (c) or to specify control limits for the c Chart. For the latter you can enter values for the Upper, Centerline, and Lower limits.

Use the Exclude... command on the dialog box to choose the subgroups you want to exclude from the analysis. When you click the button, the Exclude/Include Options dialog box displays.

c Chart Report

The c Chart Report option creates a report based on your selection on the c Chart Report Options dialog box. You can create a report of all the observations; of the observations beyond the control limits; or of the observations that were excluded from the analysis. The report lists the observation, and the values for c (see Figure 4-34). Points that are beyond the limits are noted with an asterisk; points that are excluded are noted by an X.

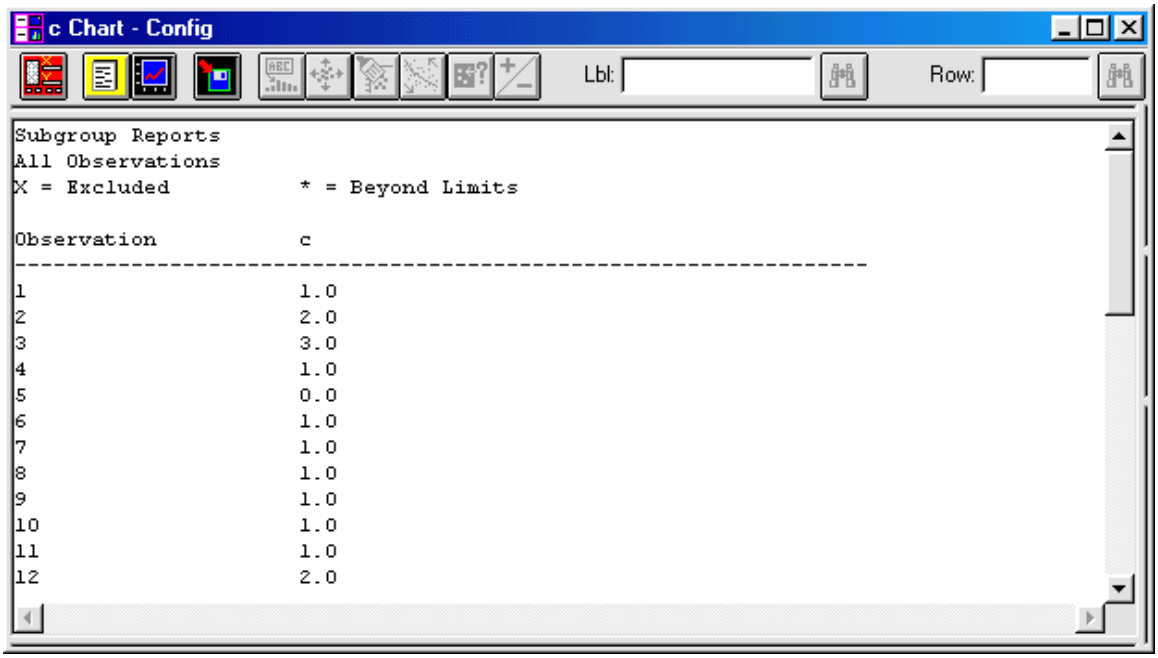

Figure 4-34. c Chart Report

Use the *C Chart Report Options* dialog box to choose the type of reports that will be included: All Observations, Observations Beyond Limits, or Excluded Observations (see Figure 4-35).

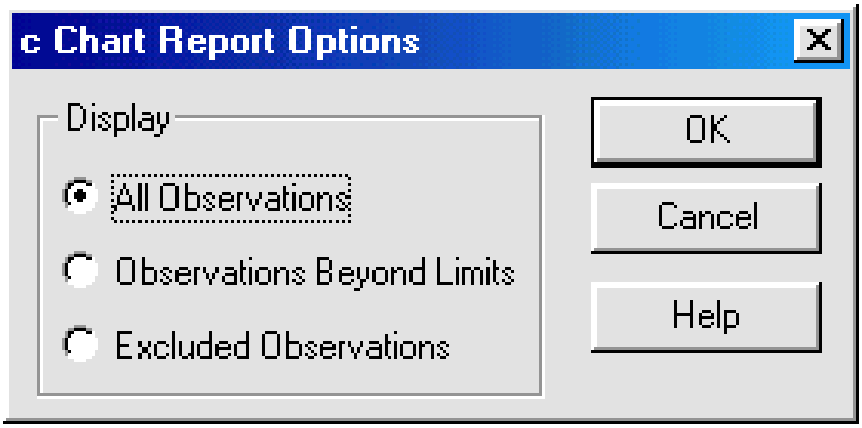

Figure 4-35. c Chart Report Options Dialog Box

Runs Tests

The Runs Tests option searches for and identifies any unusual patterns in the data. The tests are helpful in detecting processes that are slowly drifting away from the target (even though no points may fall outside the control limits) (see Figure 4-36). The report displays the subgroup at which the unusual pattern was detected as well as the rule that was violated. A nonrandom pattern indicates that a process is out of control.

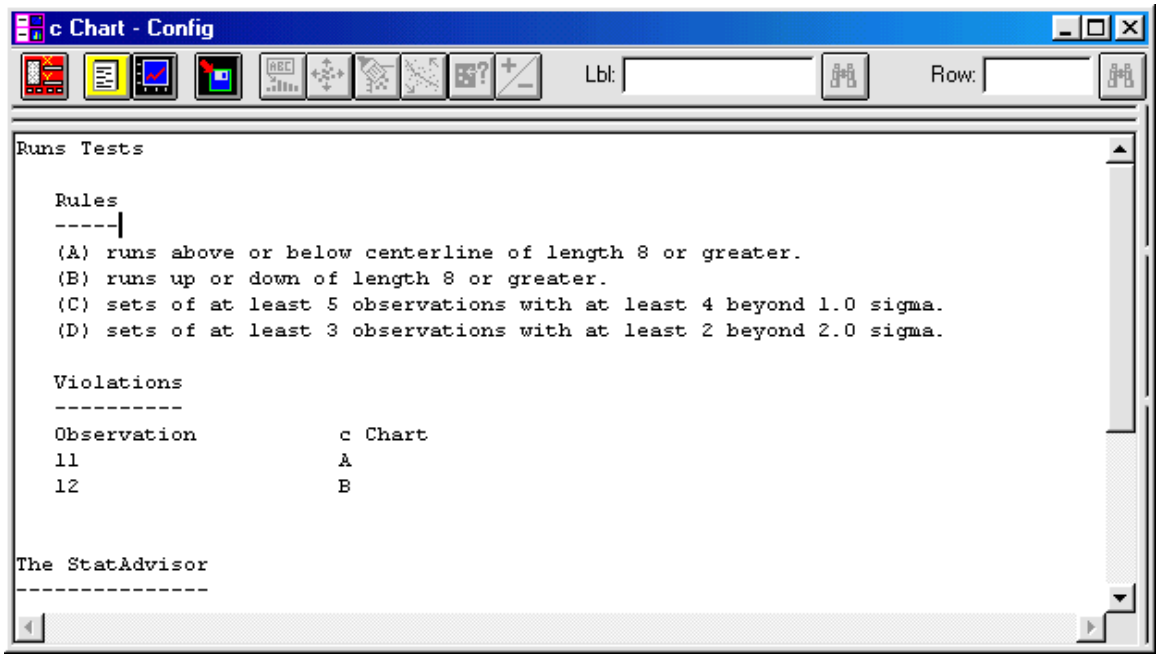

Figure 4-36. Runs Tests

Use the *Runs Tests Options* dialog box to indicate the guidelines for the tests and the violation rules. See Figure 4-7 for an example of this dialog box.

Graphical Options

c Chart

The c Chart option creates a plot of the nonconformities for each of the observations. A process is considered out of control if points are shown outside the control limits, or if points are shown within the control limits, but arranged in a nonrandom sequence (see Figure 4-37).

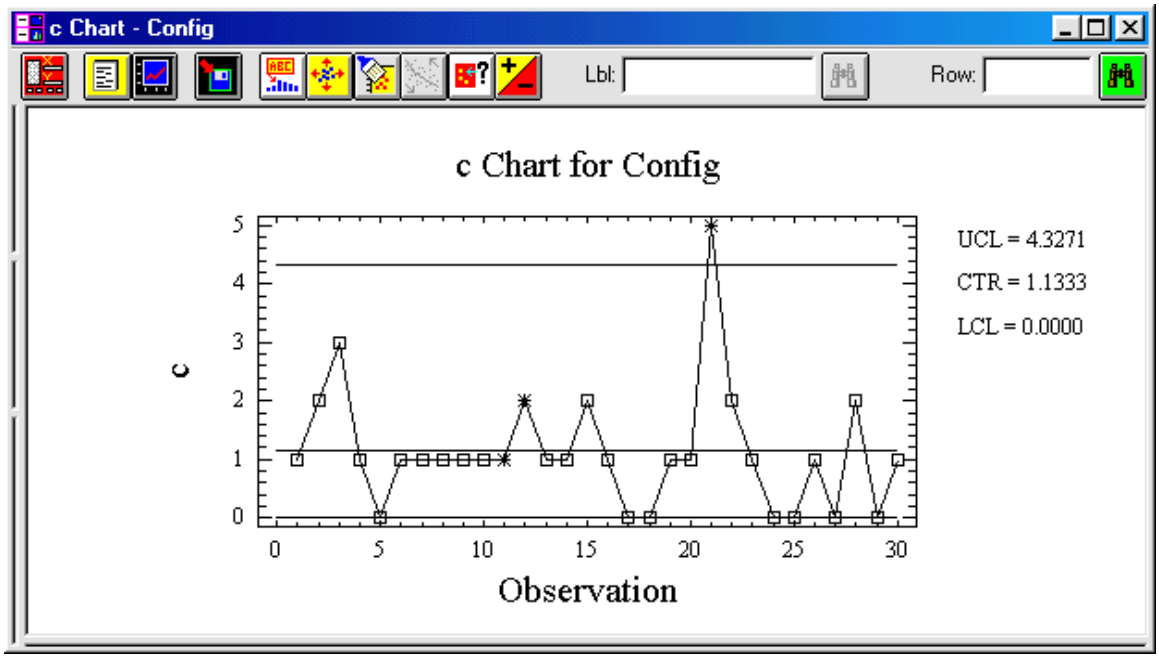

Figure 4-37. c Chart

Use the *Control Chart Options* dialog box to indicate if outer and inner warning limits should be calculated, and if so, to enter a value for sigma. You also indicate if the moving average and exponentially weighted moving average should be calculated, and if so, to enter values for the order and lambda, respectively. You also enter a value for the number of decimal places for displaying the limits, and indicate if you want the rule violations noted. See Figure 4-10 for an example of this dialog box.

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point that is plotted on the control chart will remain inside the control limits as a function of the true frequency (see Figure 4-38). It is useful for judging the effectiveness of a control chart in detecting when a process drifts away from the target (see Figure 4-26). The X-axis shows the shift in the average count; the Y-axis the probability of not detecting the shift.

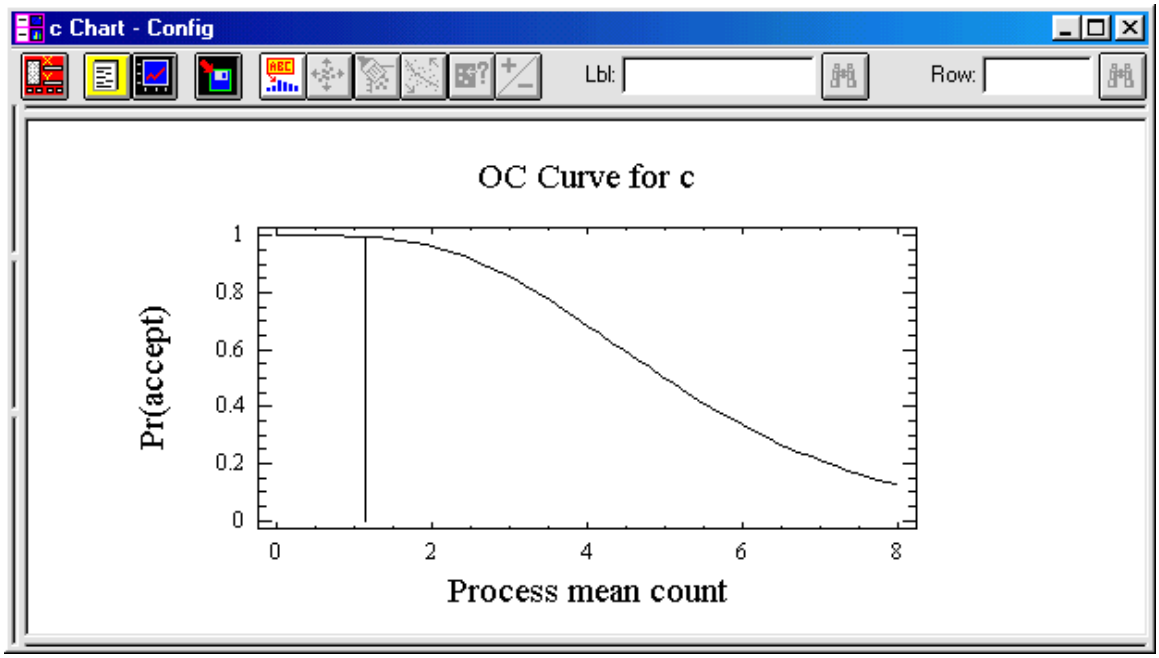

Figure 4-38. OC Curve

ARL Curve

The ARL Curve option creates a plot that shows the average run length (ARL) as a function of the process mean count (see Figure 4-39). For example, if the process is actually running at Centerline, the chart should generate an out-of-control signal on an approximate average based on the number of samples. If the process moves away from the centerline, the average run length will change. The plot is helpful in choosing an adequate sampling plan to monitor the process.

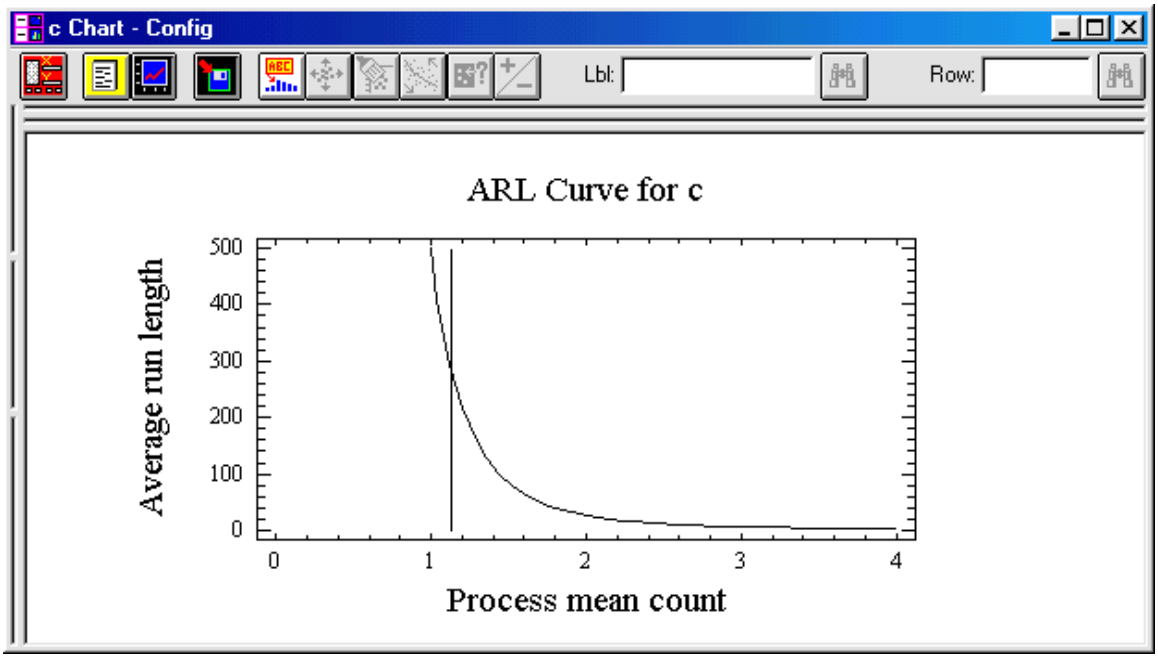

Figure 4-39. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to select the results you want to save. There are four selections: Counts, Labels, Mean c, and Sigma.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

References

AT&T. 1956. *Statistical Quality Control Handbook, Select Code 700444.* Indianapolis: AT&T Technologies.

Duncan, A. J. 1974. *Quality Control and Industrial Statistics*, fourth edition. Homewood, Illinois: Richard D. Irwin, Inc.

Grant, E. L. and Leavenworth, R. S. 1980. *Statistical Quality Control*, fifth edition. New York: McGraw-Hill, Inc.

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Chapter 5

USING TIME-WEIGHTED CHARTS

Time-weighted charts are similar to control charts except in the following ways:

- time-weighted charts incorporate past history of a process into charted points

- time-weighted charts generally are more sensitive to small, gradual changes in a process

- control limits for time-weighted charts are based on moving statistics.

You can overlay moving averages or moving ranges onto a control chart using the Control Chart Options dialog box in any of the analyses for variables control charts or attributes control charts. *For more information on control charts, see Chapter 3, Determining Statistical Control of Variable Data, Chapter 4, Determining Statistical Control of Attribute Data, and Chapter 7, Using Special Purpose SPC Control Charts.*

The STATGRAPHICS *Plus* Quality and Design product contains eight time-weighted charts that are based on subgroup statistics or individual observations: Moving Average Chart, MA Individuals Chart, EWMA Chart, EWMA Individuals Chart, CuSum Chart (V-Mask), CuSum Individuals Chart (V-Mask), CuSum Chart (H-K), and CuSum Individuals Chart (H-K).

Using the Moving Average Chart Analysis

The primary purpose of the analysis is to control current processes; however, you also use the analysis to incorporate past history of a process into charted points. A moving average chart is particularly useful in production lines that require longer times to produce a single item. By adding each new item to the subgroup as the item is produced, you always have an up-to-date picture of the process.

A moving average is a way to smooth a curve that represents data. STATGRAPHICS *Plus* replaces individual observations with the mean of each observation and the observations on either side of it. For example, if a variable has 10 observations, the program averages the first five observations. It then creates a second subgroup by dropping the first observation, adding the sixth, and calculating the average. The third subgroup drops the second observation, adds the seventh, calculates the average, and so on.

To Access the Moving Average Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... TIME-WEIGHTED CHARTS... MOVING AVERAGE CHART... from the Menu bar to display the Moving Average Chart Analysis dialog box shown in Figure 5-1.

2. Complete the dialog box and click OK to display the Analysis Summary and MA Chart in the Analysis window.

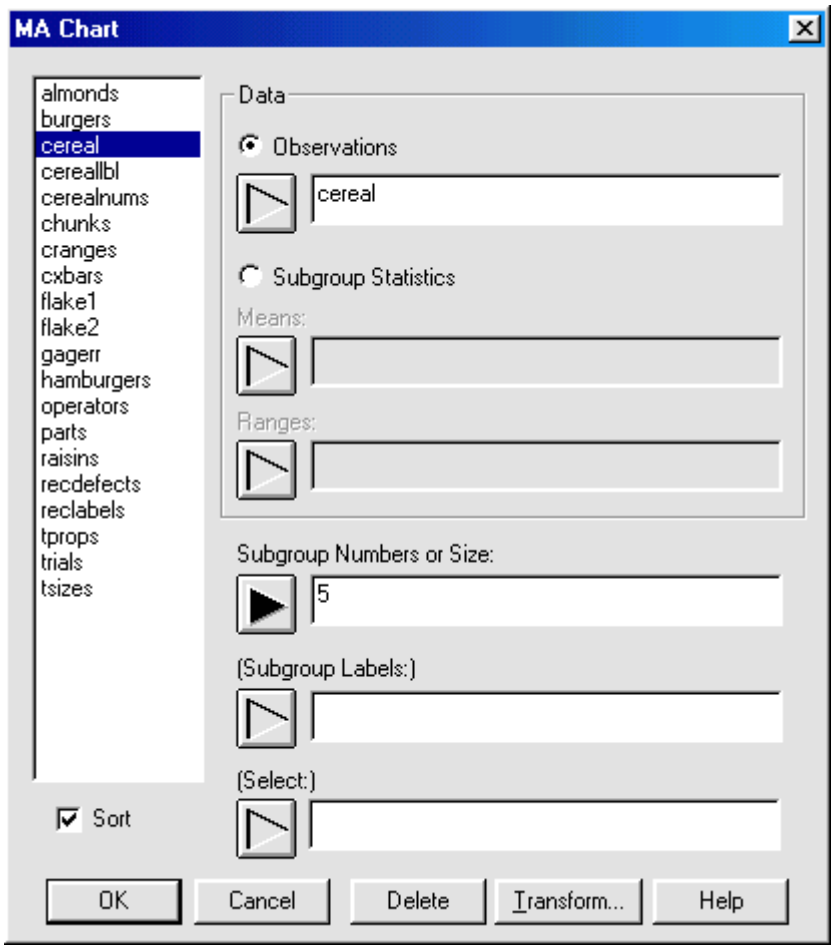


Figure 5-1. Moving Average Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 5-2). The program constructs the control charts under the assumption that the data come from a normal distribution

with values for the mean and standard deviation, which are estimated from the data.

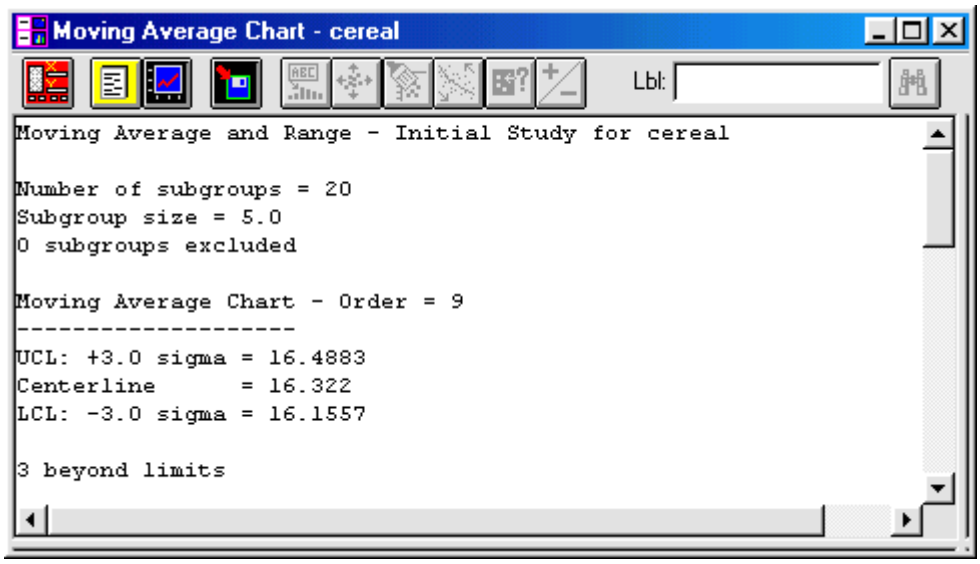


Figure 5-2. Analysis Summary

For both the Moving Average Chart and the Range Chart, the report displays the values for the upper and lower control limits, the centerline, and the number of subgroups beyond the limits. It also shows the number of subgroups, the subgroup size, and the number of subgroups excluded from the study. It provides estimates for the process mean, process sigma, and the mean range. For a control-to-standard study, the report includes the standard statistics.

Use the *Moving Average Chart Options* dialog box to indicate if the study will be an initial or a control to standard; to enter a number that will be used to calculate each point; and to indicate the location of the MA and the Range control limits and the numbers that will be used to calculate them (see Figure 5-3). For a control-to-standard study, you can specify the values that will be used for the mean and sigma parameters. This dialog box is available from all the tabular and graphical panes so you can make changes that will affect the analysis.

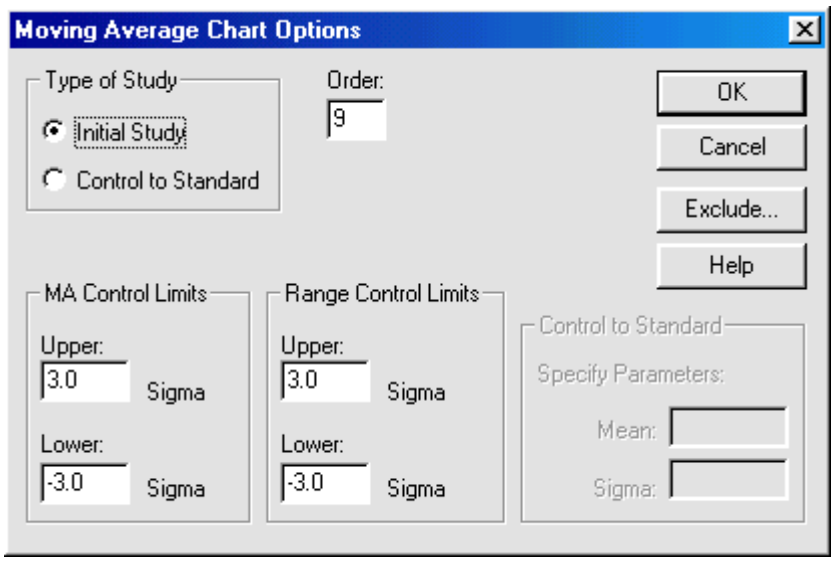


Figure 5-3. Moving Average Chart Options Dialog Box

MA Chart Report

The MA Chart Report option creates a report based on your selection on the MA Chart Report Options dialog box. You can create a report of all the subgroups; of all the subgroups beyond the control limits, of the moving averages beyond the limits, of the ranges beyond the limits, or of all the subgroups that were excluded from the analysis. The report lists the subgroups, subgroup size, moving average, and the range. Figure 5-4 is a report of all the subgroups.

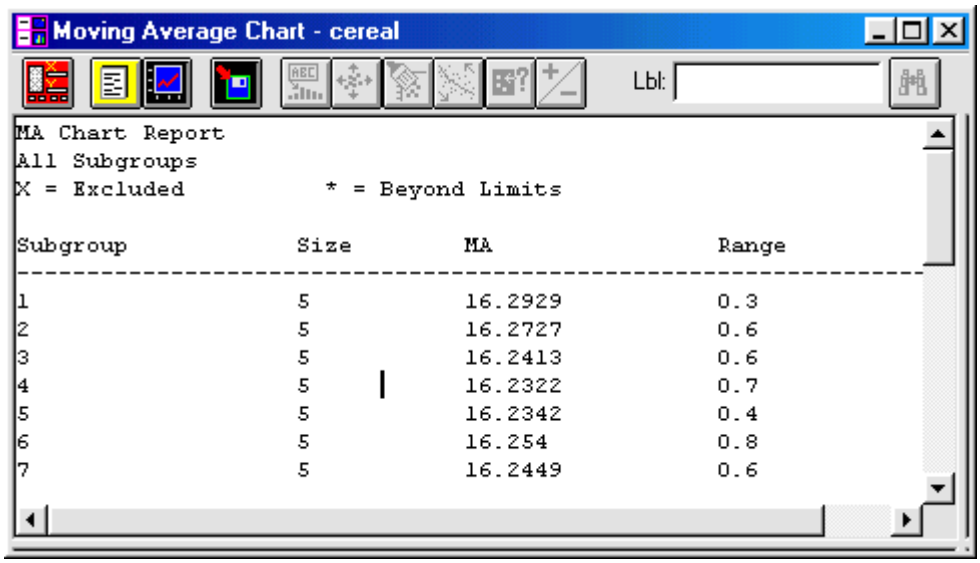


Figure 5-4. MA Chart Report

Use the *MA Chart Report Options* dialog box to choose the report you want to create (see Figure 5-5).

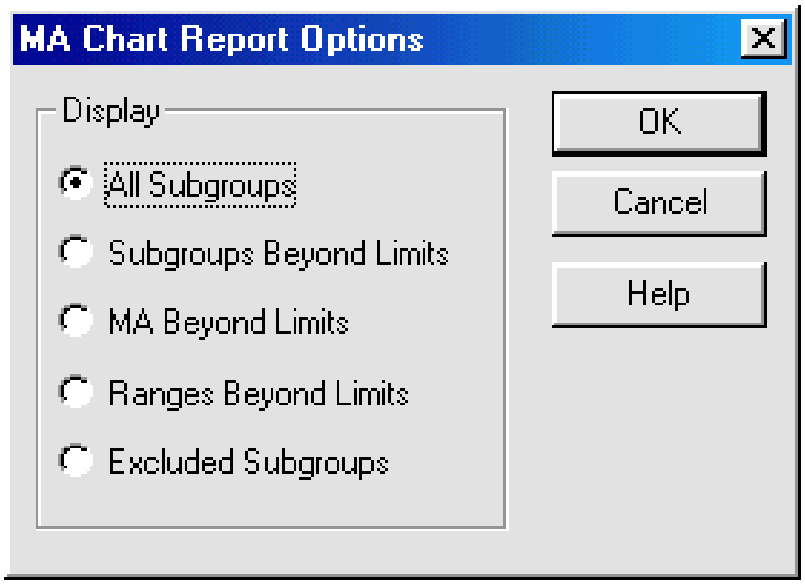


Figure 5-5. MA Chart Report Options Dialog Box

Capability Indices

The Capability Indices option calculates several process control indices based on the estimated process mean and standard deviation (see Figure 5-6). These indices help determine the capability of a process to produce products that must meet a quality standard.

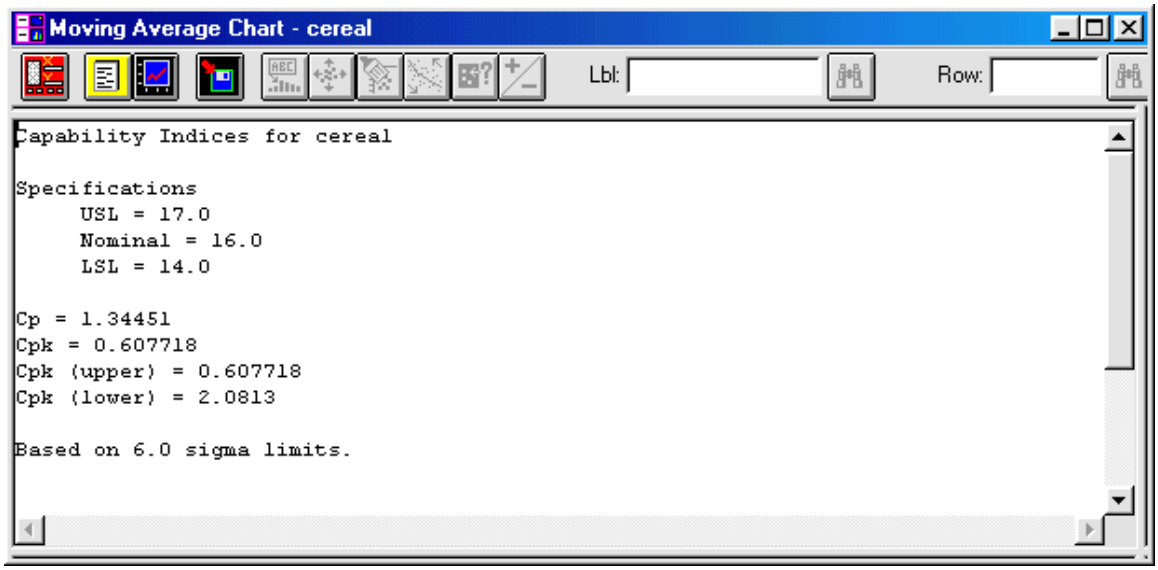


Figure 5-6. Capability Indices

Note: The capability indices will not be calculated until you enter values for the USL, Nominal, and LSL values on the Process Capability Indices Options dialog box.

Use the *Process Capability Indices Options* dialog box to choose the indices you want to include, and to enter values for upper and lower specification limits and the nominal (see Figure 5-7).

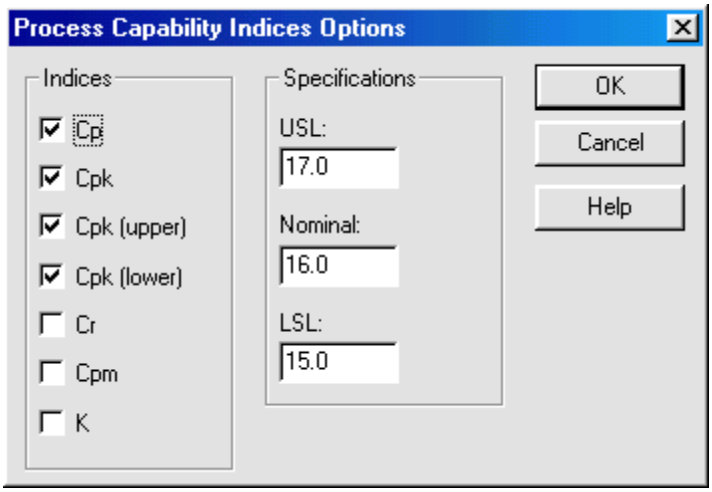


Figure 5-7. Process Capability Indices Options Dialog Box

Graphical Options

Moving Average Chart

The Moving Average Chart option creates a plot of the moving averages for each of the subgroups, and identifies the subgroups beyond the control limits (see Figure 5-8).

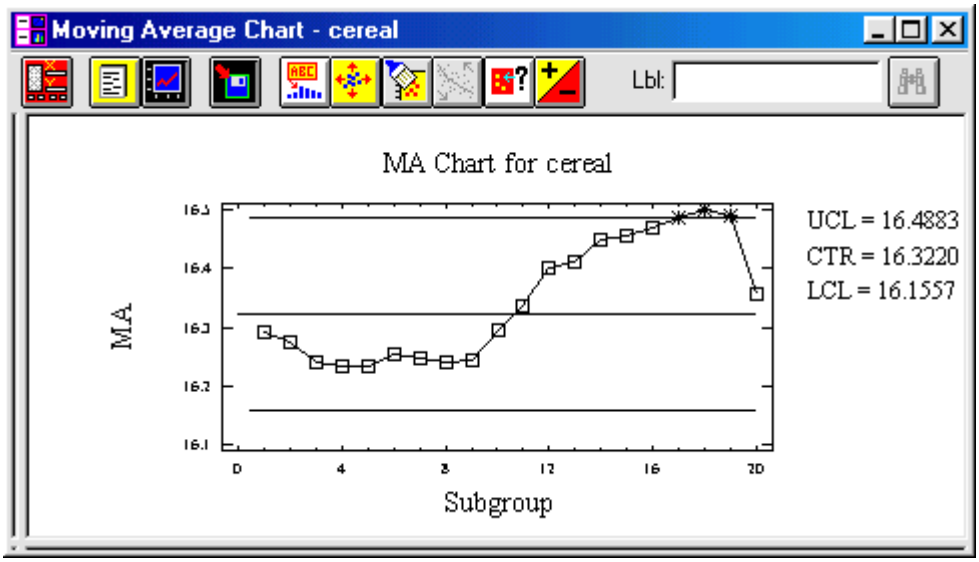


Figure 5-8. Moving Average Chart

Use the *Moving Average Control Chart Options* dialog box to indicate if you want to plot the original data, and to enter the number of decimal places that will be used for displaying the limits (see Figure 5-9).

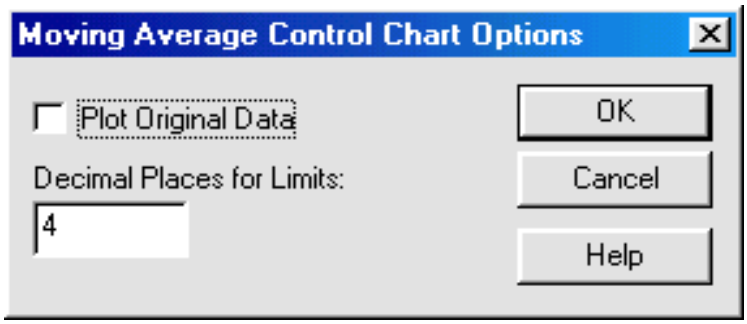


Figure 5-9. Moving Average Control Chart Options Dialog Box

Range Chart

The Range Chart option creates a plot of the ranges for each of the subgroups and shows the points that are beyond the control limits (see Figure 5-10).

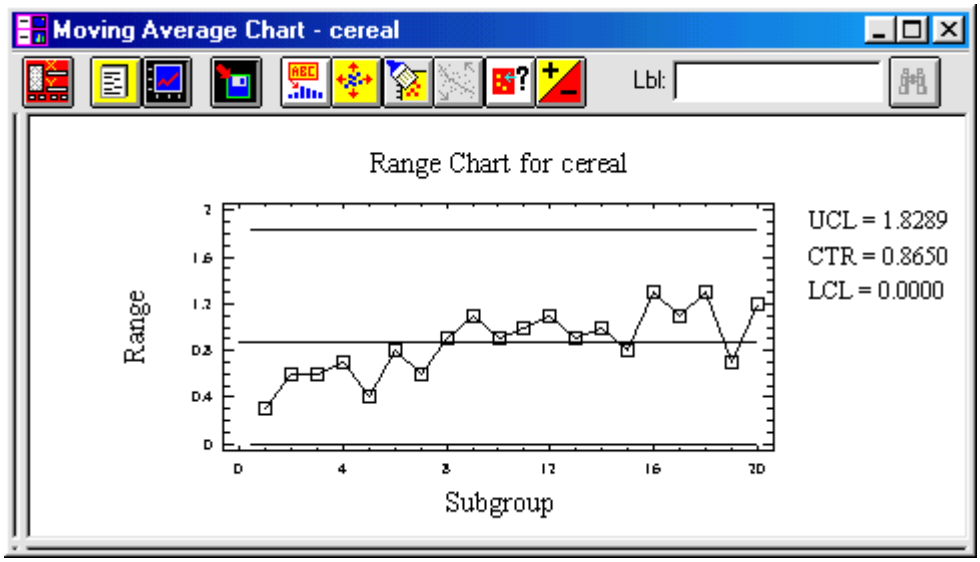


Figure 5-10. Range Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot the outer and or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; to indicate if you want the simple moving average of the subgroup statistics superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the subgroup statistics superimposed on the chart, and if so, to

enter a value for lambda; and to enter the number of decimal places that will be used for displaying the limits (see Figure 5-11).

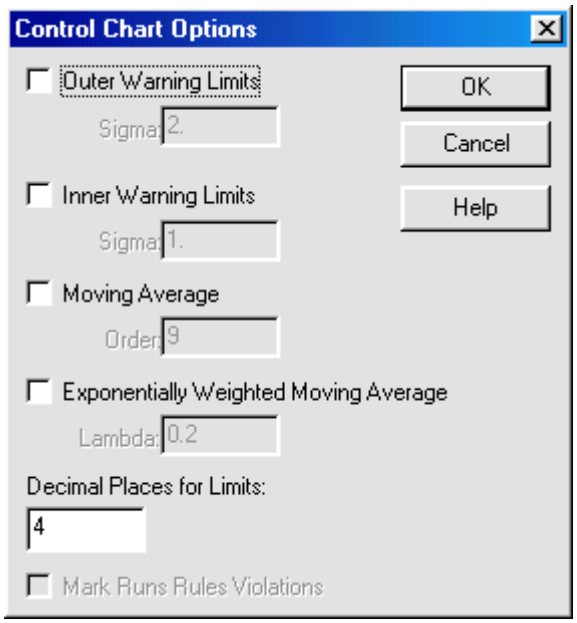


Figure 5-11. Control Chart Options Dialog Box

Tolerance Chart

The Tolerance Chart option creates a plot of the individual values for the variable, organized by subgroup (see Figure 5-12). The horizontal line indicates the grand mean of the observations. The vertical lines indicate the subgroup ranges. Because you use this option to examine individual observations, the chart is available only when you select Observations from the Data options on the Analysis dialog box.

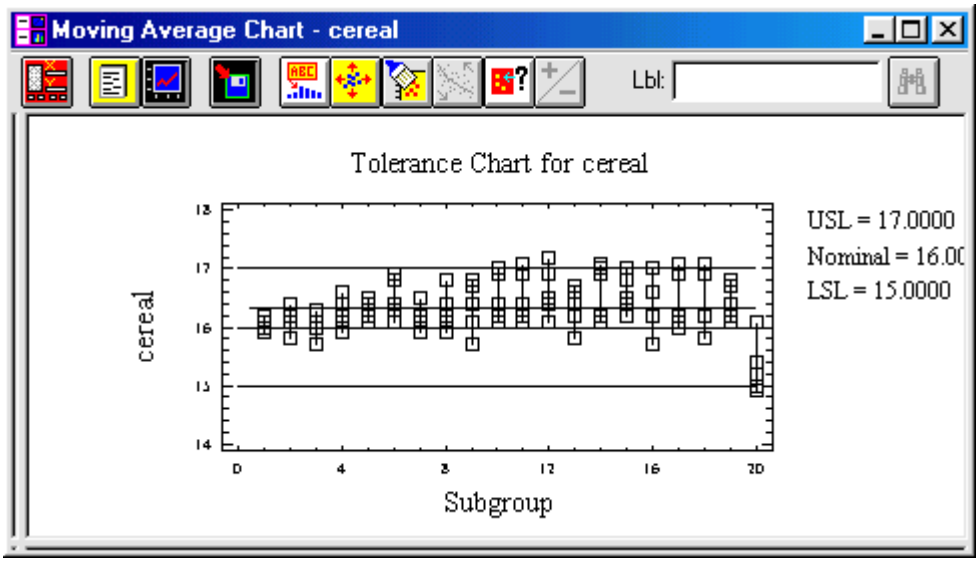


Figure 5-12. Tolerance Chart

Use the *Tolerance Chart Options* dialog box to enter values for the upper, lower, and nominal specifications, to indicate if points or the nominal will be plotted; and to enter the number of decimal places that will be used for displaying specification limits (see Figure 5-13).

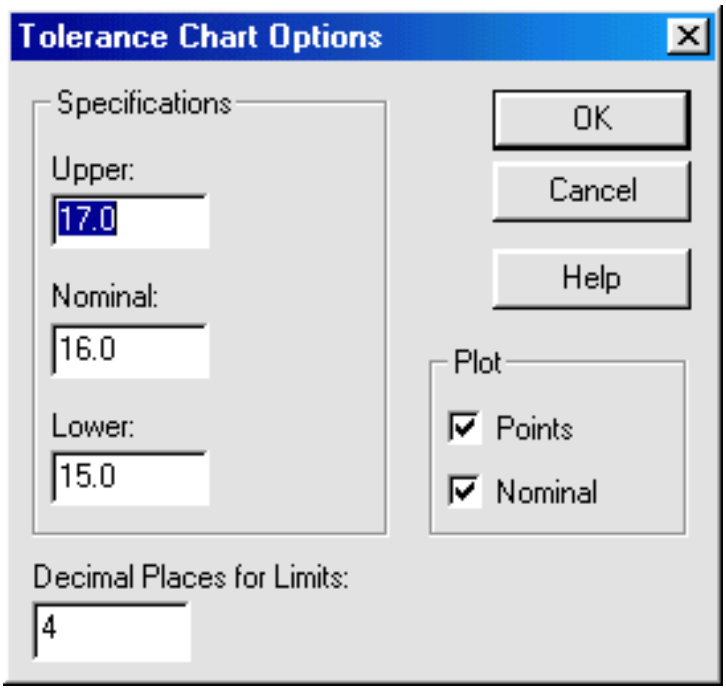


Figure 5-13. Tolerance Chart Options Dialog Box

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point plotted on the control chart will remain inside the control limits as a function of the true process mean (see Figure 5-14). In other words, it plots the probability that there will not be a signal from the chart, even though the process is not at the assumed center. The results are useful when you need to determine the effectiveness of the control chart in detecting drifts in the process away from the target. The X-axis shows the shift in the average; the Y-axis shows the probability of not detecting the shift.

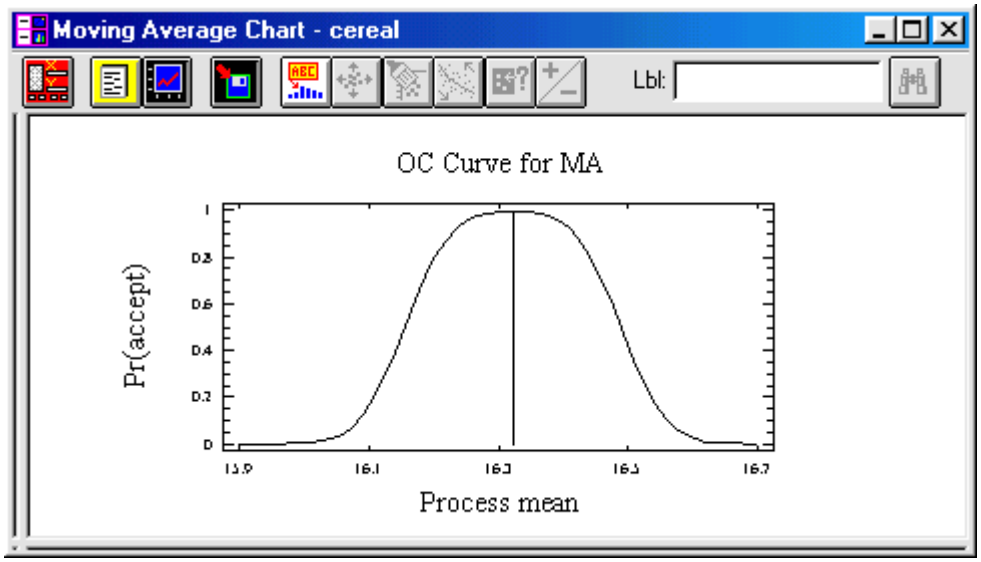


Figure 5-14. OC Curve

ARL Curve

The ARL (Average Run Length) Curve option creates a plot that shows the average run length as a function of the process mean (see Figure 5-15). For example, if the process is actually running at the centerline, the chart will not create an out-of-control signal on average for several samples. If the process moves away from the centerline, the average run length will change accordingly. The plot is helpful when you need to select an adequate sampling plan to monitor the process.

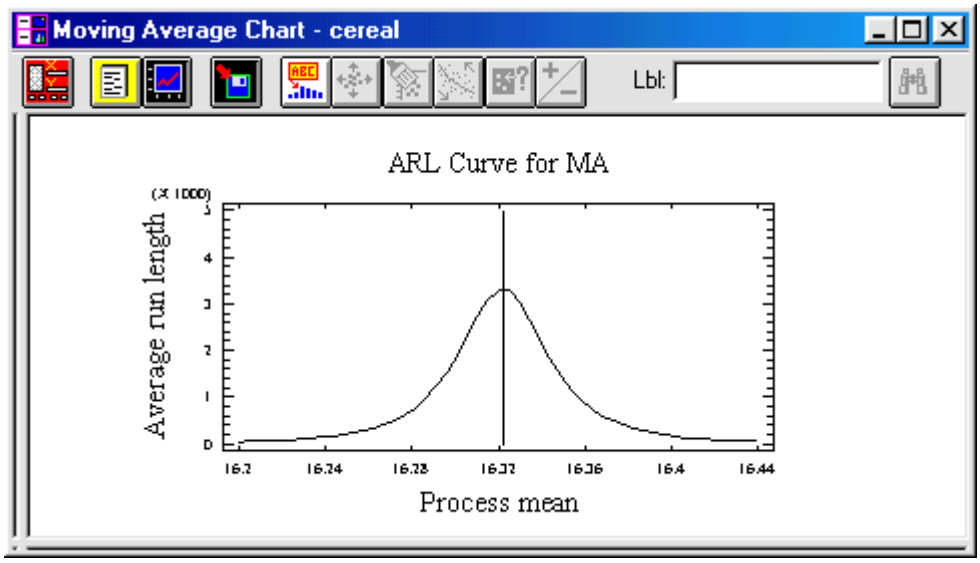


Figure 5-15. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are six selections: Moving Averages, Ranges, Sizes, Labels, Process Mean, and Process Sigma.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the Moving Average Individuals Chart Analysis

The Moving Average Individuals Chart Analysis is a time-weighted chart that allows you to analyze the moving averages of individual observations. You use this analysis to produce a Moving Average Chart and an MR(2) Chart for the moving ranges of two successive observations at one time. You can perform an initial study to estimate the control limits and set a standard by which the process will be measured. Then you use a control-to-standard study and enter parameters to test whether the process meets the standard.

To Access the Moving Average Individuals Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... TIME-WEIGHTED CHARTS... MA INDIVIDUALS CHART... from the Menu bar to display the Analysis dialog box shown in Figure 5-16.

2. Complete the dialog box and click OK to display the Analysis Summary and the MA Individuals Chart in the Analysis window.

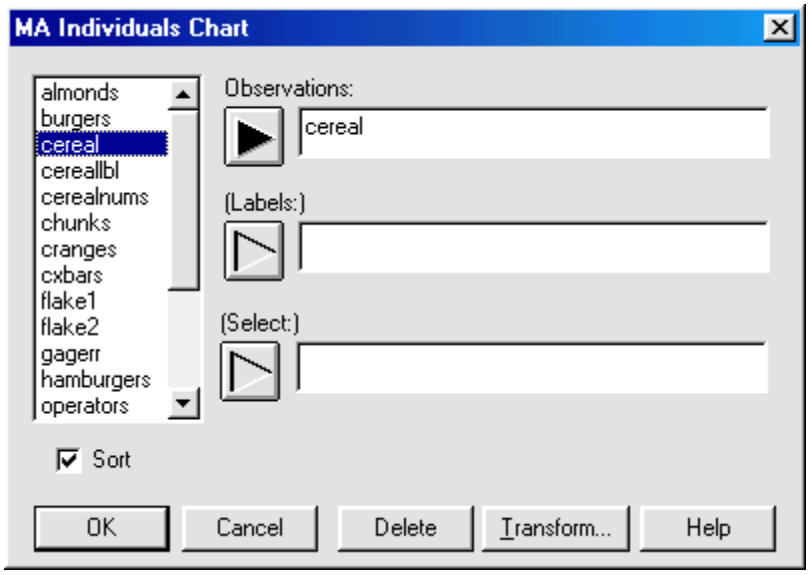


Figure 5-16. MA Individuals Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 5-17). The program constructs the control charts under the assumption that the data come from a normal distribution with values for the mean and standard deviation, which are estimated from the data.

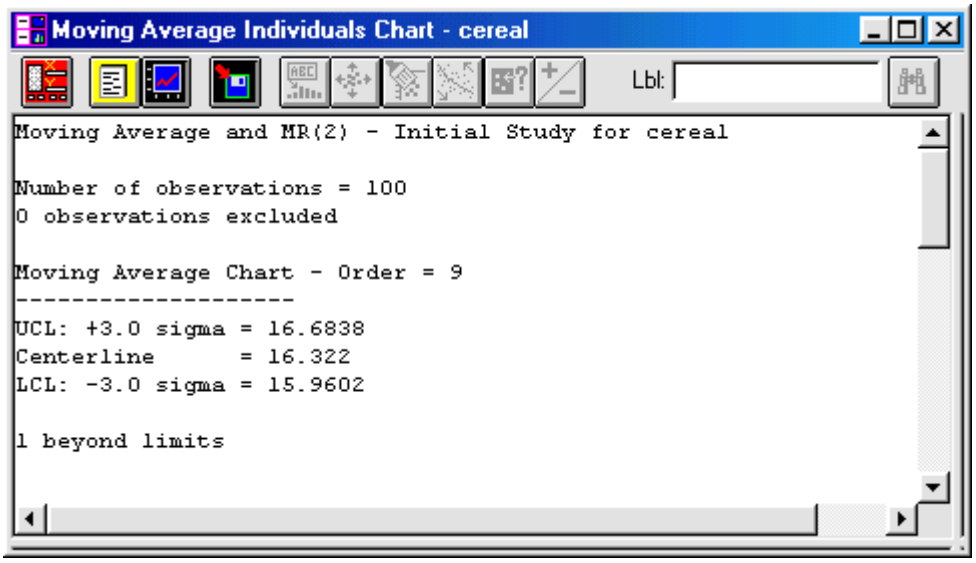


Figure 5-17. Analysis Summary

For the Moving Average Chart and the MR(2) Chart, the report displays the values for the upper and lower control limits, the centerline, and the number of observations beyond the limits. The report also shows the number of observations, and the number of observations excluded from the study. It provides estimates for the process mean, process sigma, and Mean MR(2). For a control-to-standard study, the report includes the standard statistics.

Use the *MA Individuals Chart Options* dialog box to indicate if the study will be an initial or a control to standard; to enter the number of observations that will be used to calculate each point; to enter values for sigma for the upper and lower control limits for the MA Control Chart; and to enter values for sigma for the upper and lower control limits for the MR(2) Control Chart (see Figure 5-18). For a control-to-standard study, you can specify the values that will be used for the mean and sigma parameters. This dialog box is available from all the tabular and graphical panes options so you can make changes that will affect the analysis.

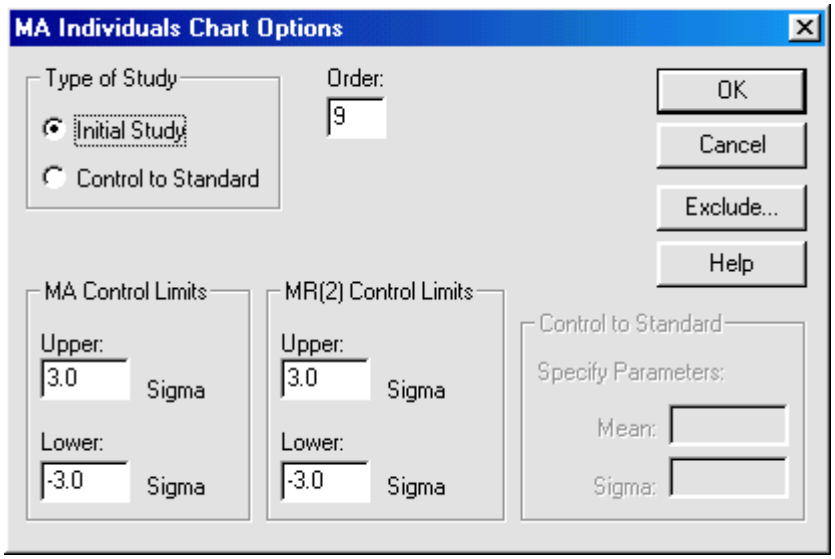


Figure 5-18. MA Individuals Chart Options Dialog Box

MA Individuals Chart Report

The MA Individuals Chart Report option creates a report of the observations based on your selection on the MA Individuals Chart Report Options dialog box (see Figure 5-19). The report shows the observation number, and values for the MA and MR(2). It notes points that are beyond the control limits with an asterisk, and points that are excluded with an X. You can create a report that displays all the observations; observations beyond the control limits, MA beyond the limits, MR(2) beyond the limits, or observations that were excluded.

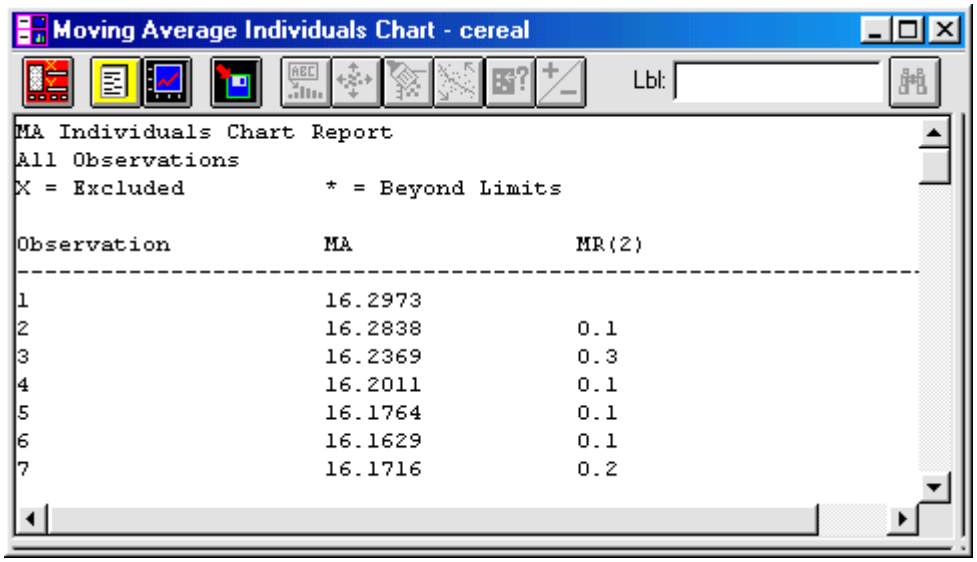


Figure 5-19. MA Individuals Chart Report

Use the *MA Individuals Chart Report Options* dialog box to choose the report you want to create (see Figure 5-20).

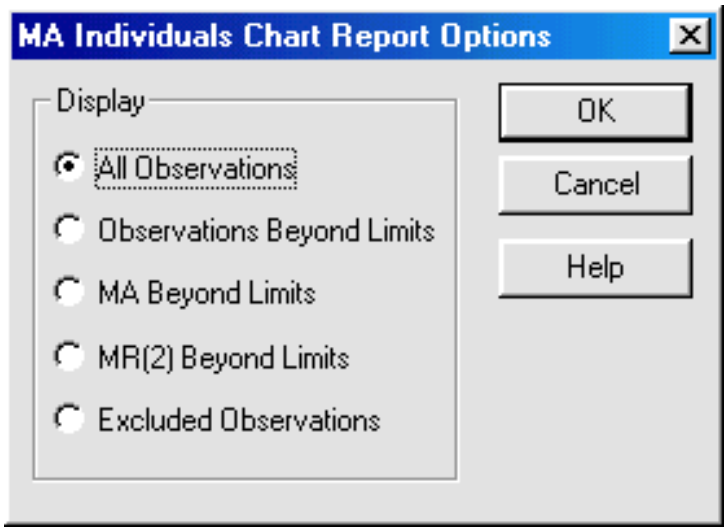


Figure 5-20. MA Individuals Chart Report Options Dialog Box

Capability Indices

The Capability Indices option calculates several process capability indices based on the estimated process mean and standard deviation (see Figure 5-21). The indices help determine the capability of the process to produce products that meet a quality standard.

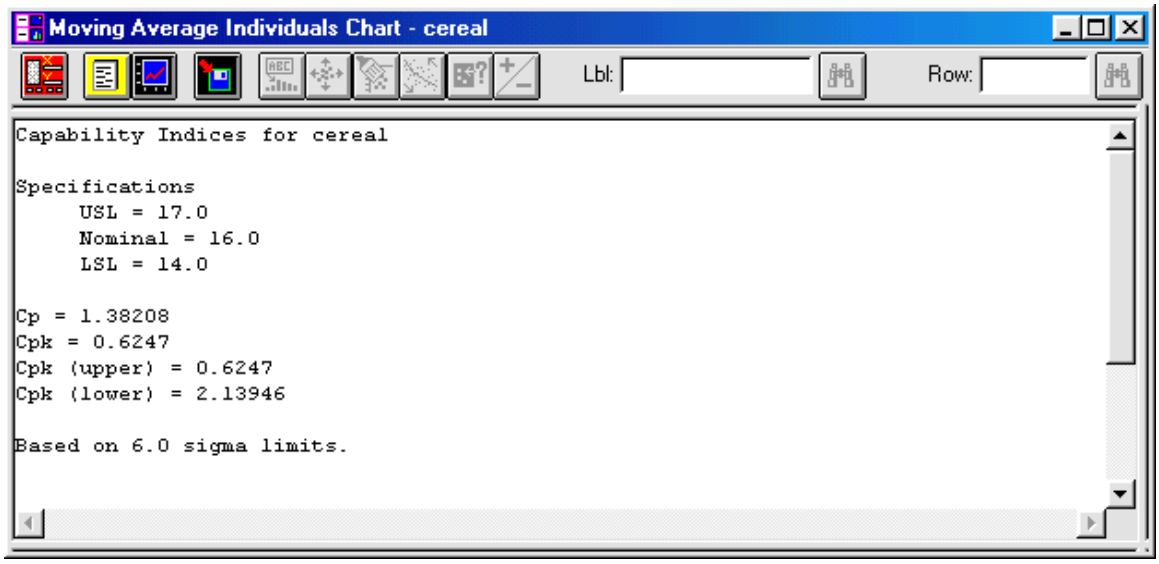


Figure 5-21. Capability Indices

Use the *Process Capability Indices Options* dialog box to choose the indices you want to include in the report, and to enter values for the upper and lower specification limits and the nominal. *See Figure 5-7 for an example of this dialog box.*

Graphical Options

Moving Average Chart

The Moving Average Chart option creates a plot of the moving averages for each of the measurements (see Figure 5-22). The chart identifies points beyond the control limits.

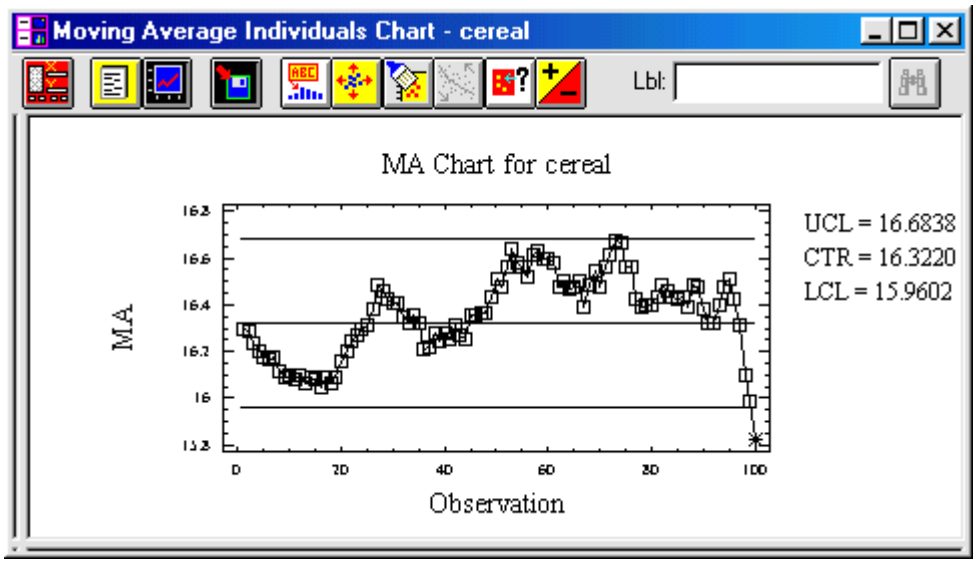


Figure 5-22. Moving Average Chart

Use the *Moving Average Chart Options* dialog box to indicate if you want to plot the original data, and to enter the number of decimal places that will be used for displaying the limits (see Figure 5-23).

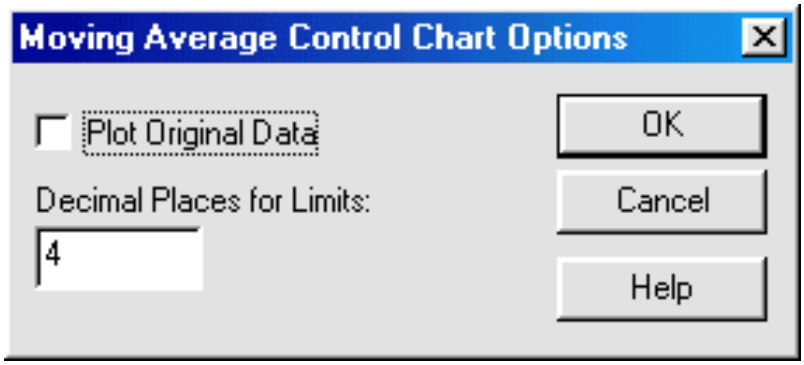


Figure 5-23. Moving Average Chart Options Dialog Box

MR(2) Chart

The MR(2) Chart option creates a plot of the moving ranges for each of the measurements (see Figure 5-24). It notes the points that are beyond the control limits.

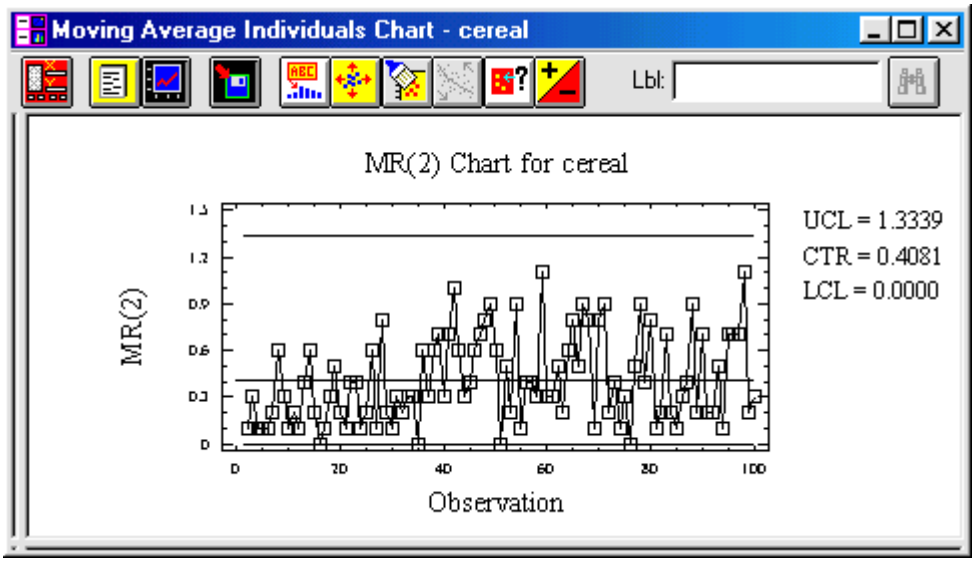


Figure 5-24. MR(2) Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; to indicate if you want the simple moving average of the subgroup statistics superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the subgroup statistics superimposed on the chart, and if so, to enter a value for lambda; to enter the number of decimal places that will be used for displaying the limits; and to indicate if violations in the runs rules should be marked. *See Figure 5-11 for an example of this dialog box.*

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point plotted on the control chart will remain inside the control limits as a function of the true process mean (see Figure 5-25). In other words, it plots the probability that there will not be a signal from the chart, even though the process is not at the assumed center. The results are useful when you need to determine the effectiveness of the control chart in detecting drifts in the process away from the target. The X-axis shows the shift in the average; the Y-axis shows the probability of not detecting the shift.

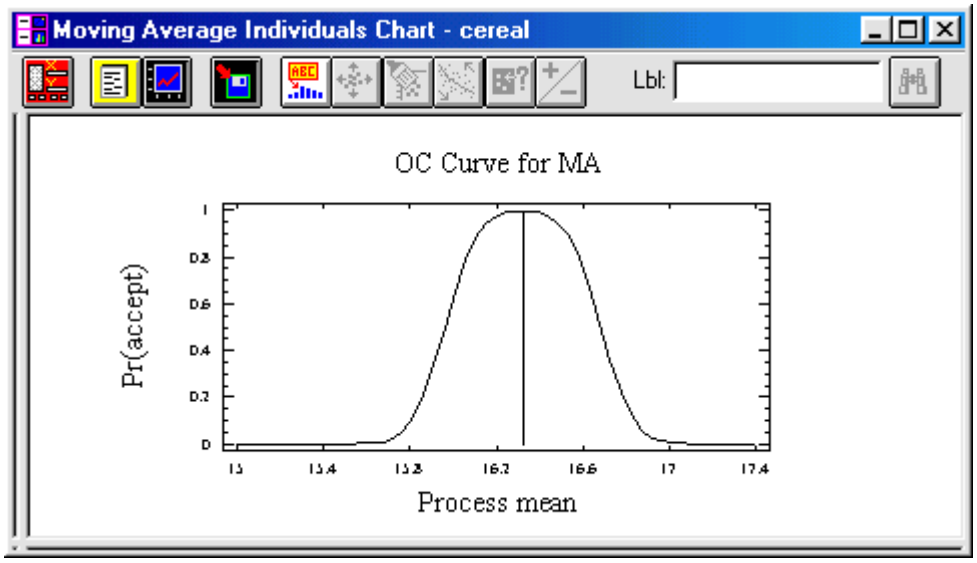


Figure 5-25. OC Curve

ARL Curve

The ARL (Average Run Length) Curve option creates a plot that shows the ARL for the MA Chart as a function of the process mean (see Figure 5-26). For example, if the process is actually running at the centerline, the chart will create an out-of-control signal on average for approximately every sample. If the process moves away from the centerline, the ARL will change accordingly. The plot is helpful when you need to select an adequate sampling plan to monitor the process.

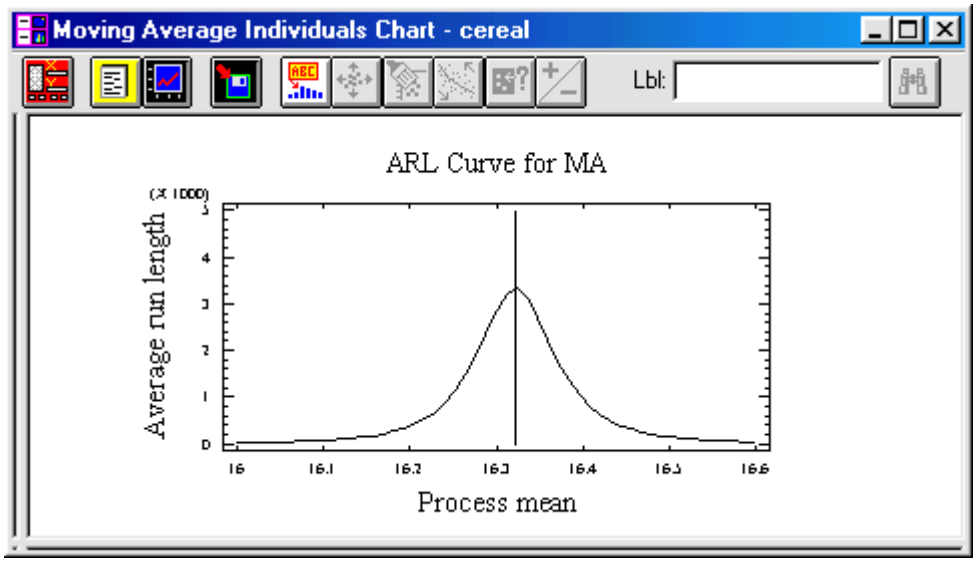


Figure 5-26. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are six selections: Moving Averages, Moving Ranges, Labels, Process Mean, Process Sigma, and Included Observations.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the EWMA Chart Analysis

EWMA (Exponentially Weighted Moving Average) Charts are generally used for detecting small shifts in the process mean -- detecting shifts of .5 sigma to 2 sigma -- much faster than Shewhart charts with the same sample size (Montgomery, 1991). However, they are slower in detecting large shifts in the process mean. In addition, you cannot use typical run tests because of the inherent dependence of data points.

You might also prefer to use an EWMA Chart when the subgroups are of size n=1. The advantage of CuSum, EWMA and Moving Average charts is that each plotted point includes several observations so you can use the Central Limit Theorem to say that the average of the points (or the moving average) is normally distributed and the control limits are clearly defined.

EWMA charts are also used to smooth the affect of known, uncontrollable noise in the data. Many accounting and chemical processes fit into this categorization; for example, while day-to-day fluctuations in accounting processes may be large, they are not purely indicative of process instability.

As with other control charts, EWMA charts are used to monitor processes over time. The charts′ X-axes are time based, so the charts show a history of the process. Therefore, your data must be time-ordered; that is, centered in the sequence from which it was generated. If the data are not time-ordered, trends or shifts in the process may not be detected but instead attributed to random variation.

These time-weighted charts incorporate the past history of a process to estimate the charted point. In this analysis, the program plots the exponentially weighted moving averages that are the weighted average of the current observation and the estimate of the previous observation. To calculate the weighted average, the current observation is multiplied by lambda and the estimate of the previous observation is multiplied by 1 - lambda.

To Access the EWMA Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... TIME-WEIGHTED CHARTS... EWMA CHART... from the Menu bar to display the Analysis dialog box shown in Figure 5-27.

2. Complete the dialog box and click OK to display the Analysis Summary and the EWMA Chart in the Analysis window.

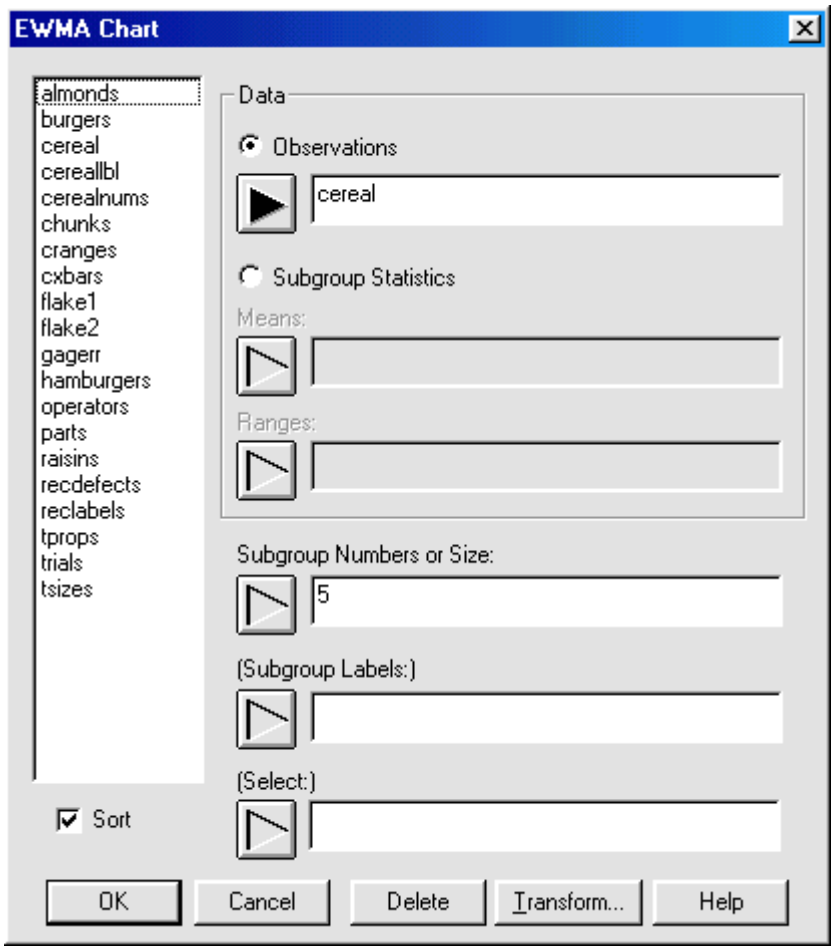


Figure 5-27. EWMA Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 5-28). The program constructs the control charts under the assumption that the data come from a normal distribution

with values for the mean and standard deviation, which are estimated from the data.

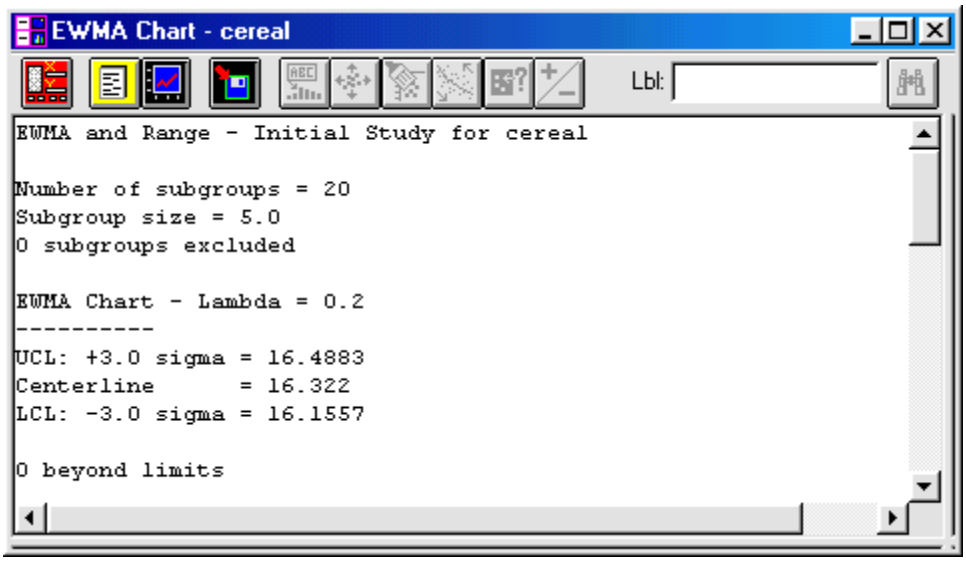


Figure 5-28. Analysis Summary

For both the EWMA Chart and the Range Chart, the report displays the values for the upper and lower control limits, the centerline, and the number of subgroups beyond the limits. It also shows the number of subgroups, the subgroup size, and the number of subgroups excluded from the study. It provides estimates for the process mean, process sigma, and the mean range. For a control-to-standard study, the report includes the standard statistics.

Use the *EWMA Chart Options* dialog box to indicate if the study will be an initial or a control to standard; to enter a number that will be used as the weighting factor that will be applied to each new subgroup average to calculate the moving average; to enter a number that will be used to calculate the average run length; and to indicate the location of the EWMA and the Range control limits and the numbers that will be used to calculate them (see Figure 5-29). For a control-to-standard study, you can specify the values that will be used for the mean and sigma parameters. This dialog box is available from all the tabular and graphical panes so you can make changes that will affect the analysis.

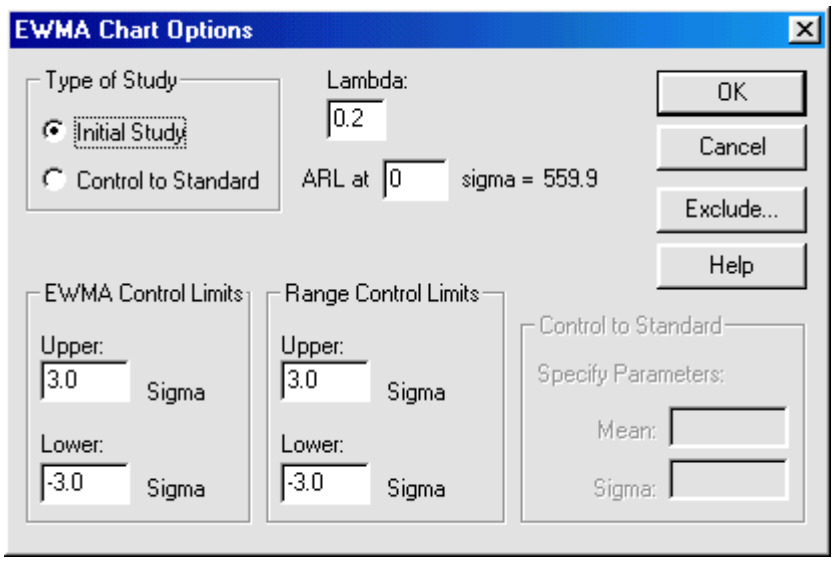


Figure 5-29. EWMA Chart Options Dialog Box

EWMA Chart Report

The EWMA Chart Report option creates a report of the subgroups based on your selection on the EWMA Chart Report Options dialog box (see Figure 5-30). You can create a report of all the subgroups; of all the subgroups beyond the control limits, of the exponentially weighted moving averages beyond the limits, of the ranges beyond the limits, or of all the subgroups that were excluded from the analysis. The report lists the subgroups, subgroup sizes, EWMA, and the range.

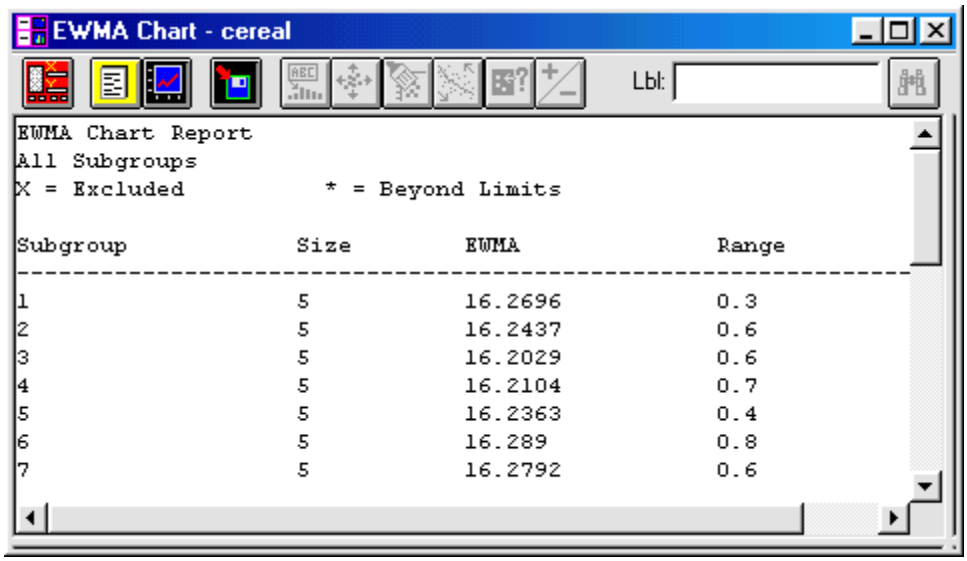


Figure 5-30. EWMA Chart Report

Use the *EWMA Chart Report Options* dialog box to choose the report you want to create (see Figure 5-31).

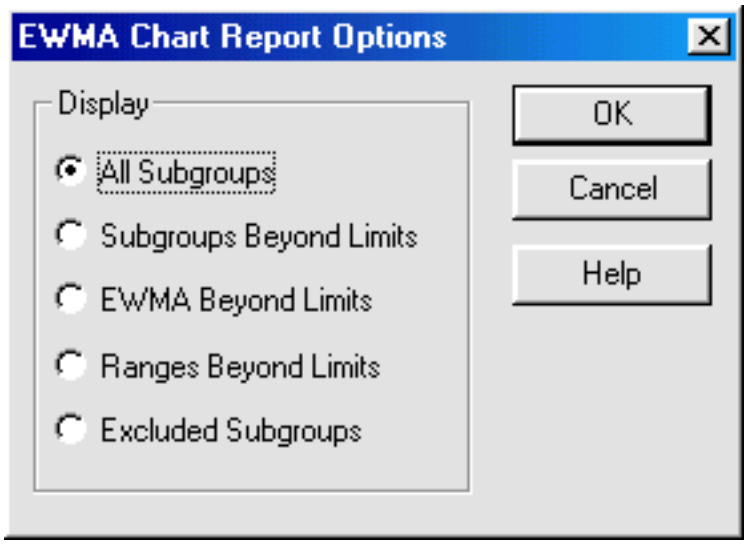


Figure 5-31. EWMA Chart Report Options Dialog Box

Capability Indices

The Capability Indices option calculates several process capability indices, based on the estimated process mean and standard deviation (see Figure 5-32). These indices help determine the capability of the process to produce products that meet a quality standard.

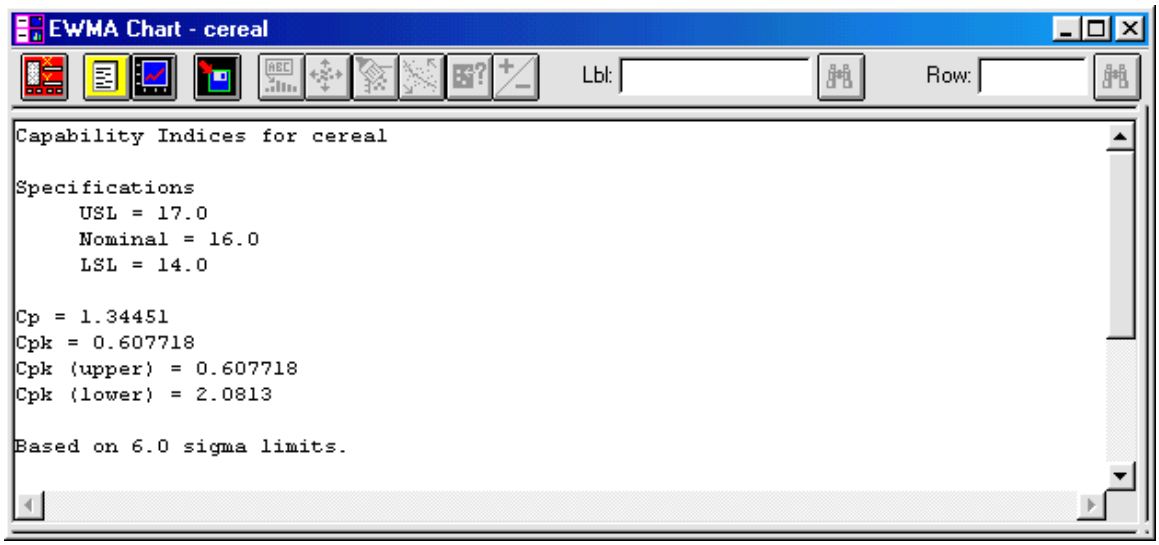


Figure 5-32. Capability Indices

Use the *Process Capability Indices Options* dialog box to choose the indices you want to include in the report, and to enter values for the upper and lower specification limits and the nominal. *See Figure 5-7 for an example of this dialog box.*

Graphical Options

EWMA Chart
The EWMA Chart option creates a plot of the exponentially weighted moving averages for each of the subgroups, and identifies the subgroups beyond the control limits (see Figure 5-33).

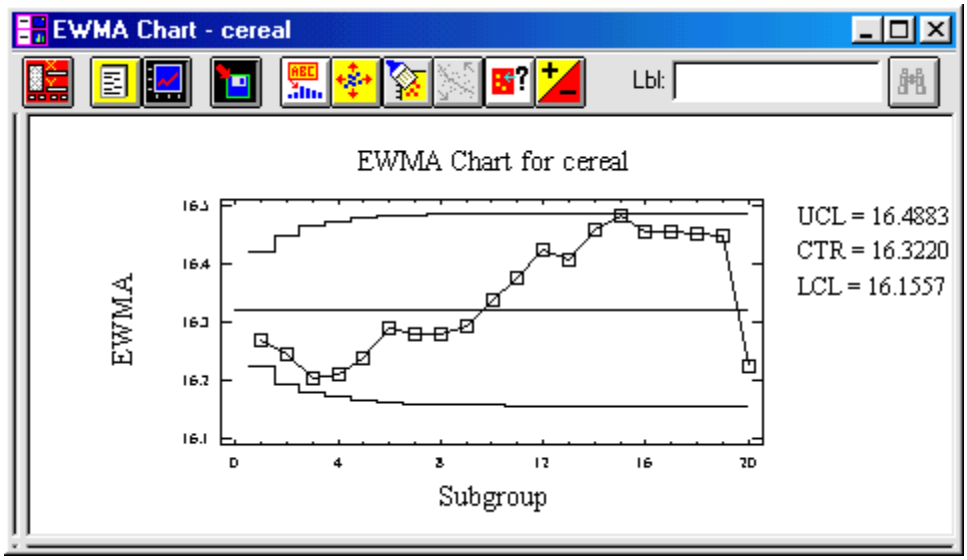


Figure 5-33. EWMA Chart

Use the *EWMA Control Chart Options* dialog box to indicate if you want to plot the original data, and to enter the number of decimal places that will be used for displaying the limits (see Figure 5-34).

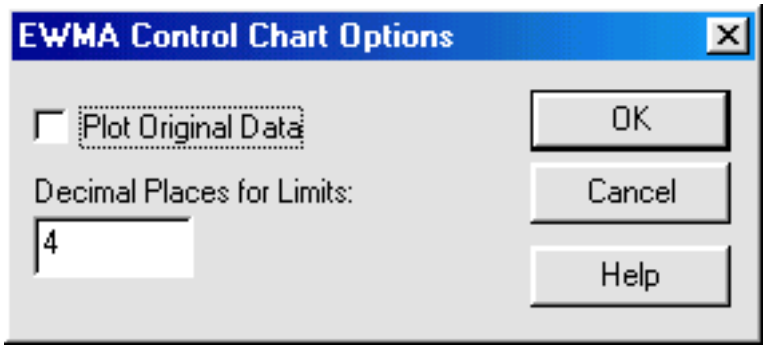


Figure 5-34. EWMA Control Chart Options Dialog Box

Range Chart
The Range Chart option creates a plot of the ranges for each of the subgroups and shows the points that are beyond the control limits (see Figure 5-35).

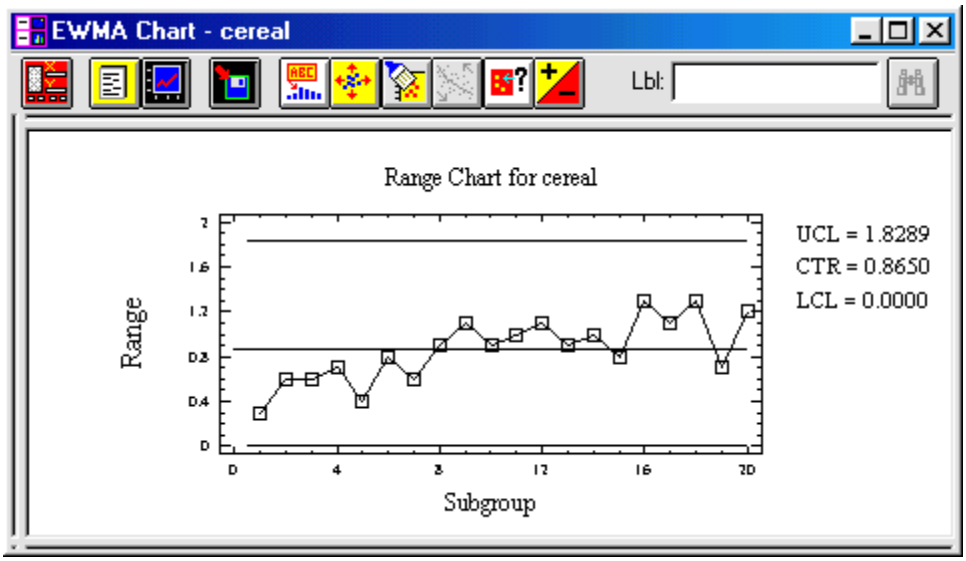


Figure 5-35. Range Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; to indicate if you want the simple moving average of the subgroup statistics superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the subgroup statistics superimposed on the chart, and if so, to enter a value for lambda; and to enter the number of decimal places that will be used for displaying the limits. *See Figure 5-11 for an example of this dialog box.*

Tolerance Chart

The Tolerance Chart option creates a plot of the individual values for the variable, organized by subgroup (see Figure 5-36). The horizontal line indicates the grand mean of the observations. The vertical lines indicate the subgroup ranges. Because you use this option to examine individual observations, the chart is available only when you select Observations from the Data options on the Analysis dialog box.

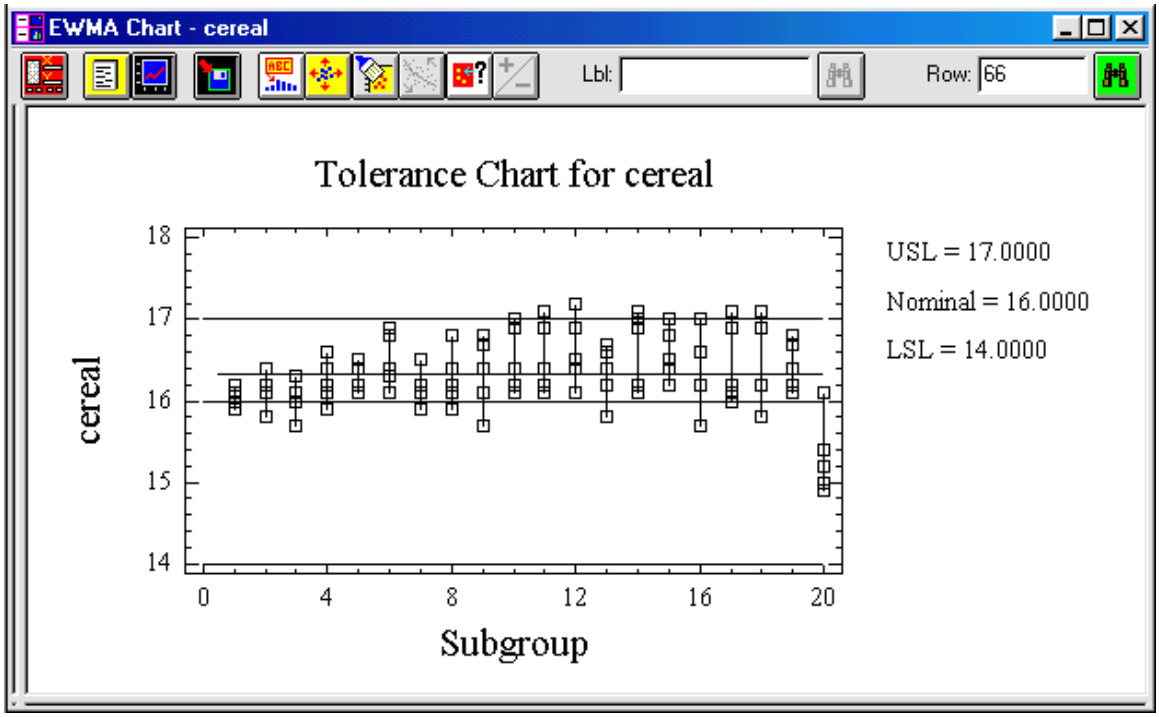


Figure 5-36. Tolerance Chart

Use the *Tolerance Chart Options* dialog box to enter values for the upper, lower, and nominal specifications, to indicate if points or the nominal will be plotted; and to enter the number of decimal places that will be used for displaying the specification limits (see Figure 5-37).

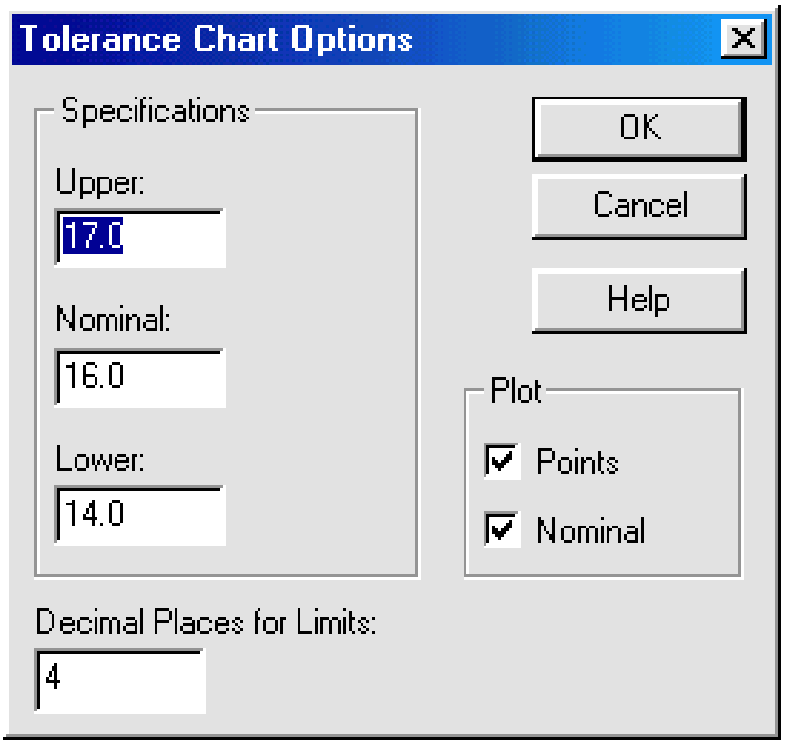


Figure 5-37. Tolerance Chart Options Dialog Box

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point plotted on the control chart will remain inside the control limits as a function of the true process mean (see Figure 5-38). In other words, it plots the probability that there will not be a signal from the chart, even though the process is not at the assumed center. The results are useful when you need to determine the effectiveness of the control chart in detecting drifts in the process away from the target. The X-axis shows the shift in the average; the Y-axis shows the probability of not detecting the shift.

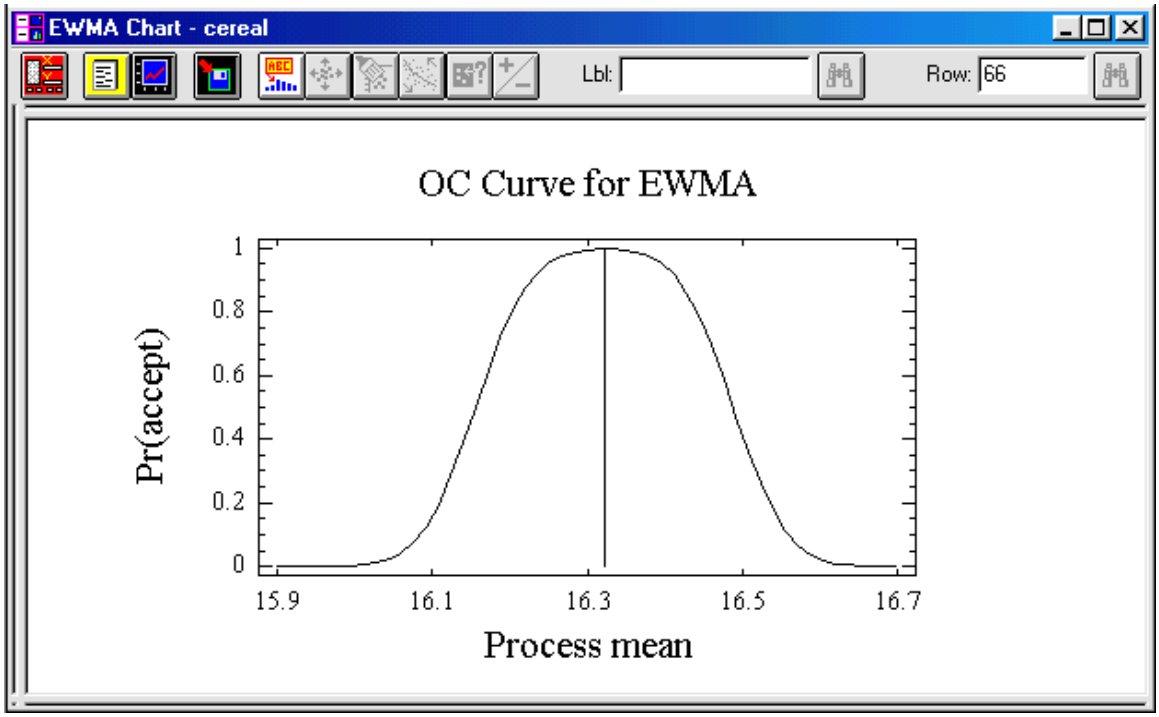


Figure 5-38. OC Curve

ARL Curve

The ARL (Average Run Length) Curve option creates a plot that shows the ARL for the EWMA Chart as a function of the process mean (see Figure 5-39). For example, if the process is actually running at the centerline, the chart will not create an out-of-control signal on average for several samples. If the process moves away from the centerline, the ARL will change accordingly. The plot is helpful when you need to select an adequate sampling plan to monitor the process.

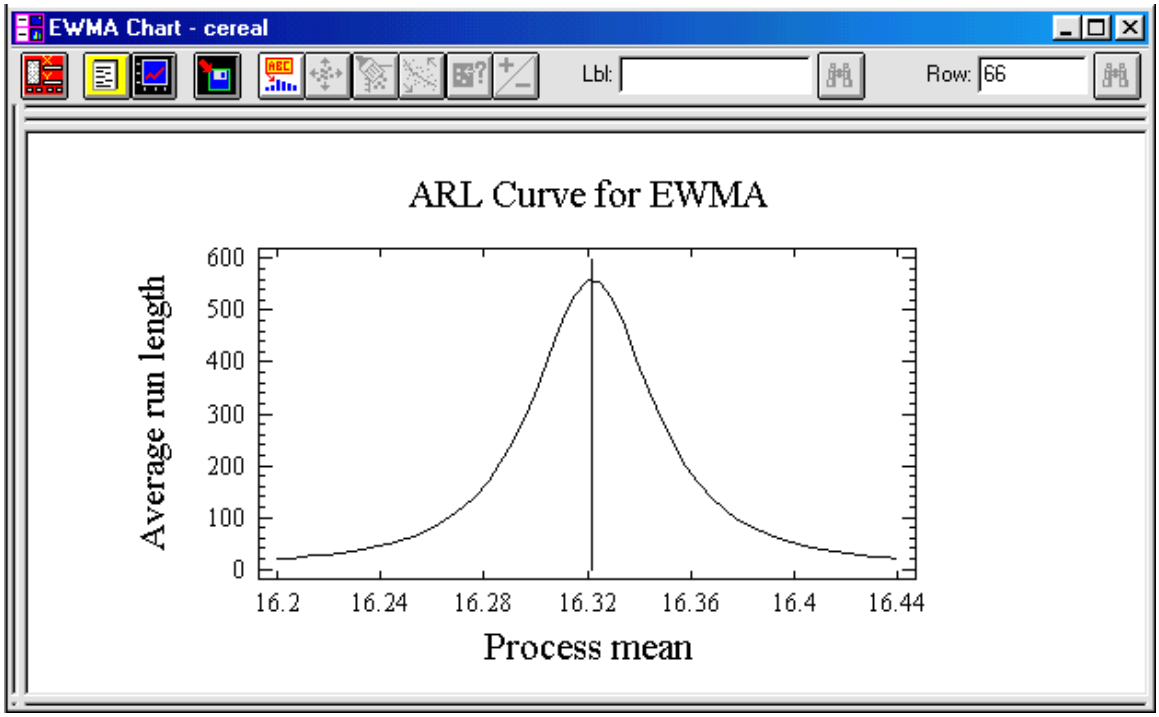


Figure 5-39. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are six selections: EWMAs, Ranges, Sizes, Labels, Process Mean, and Process Sigma.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the EWMA Individuals Chart Analysis

The EWMA Individuals Chart Analysis is a time-weighted chart that allows you to analyze the exponentially weighted moving averages of individual observations.

The analysis is insensitive to data that are not normally distributed, making it an ideal tool for individual data (subgroup size = 1). Like the EWMA Chart Analysis, you use this analysis to produce an EWMA Chart for moving averages. You can perform an initial study to estimate the control limits and set a standard by which

the process will be measured. Then you use a control-to-standard study and enter parameters to test whether the process meets the standard.

To Access the EWMA Individuals Analysis

1. Choose SPECIAL... QUALITY CONTROL... TIME-WEIGHTED CHARTS... EWMA INDIVIDUALS CHART... from the Menu bar to display the Analysis dialog box shown in Figure 5-40.

2. Complete the dialog box and click OK to display the Analysis Summary and the EWMA Chart in the Analysis window.

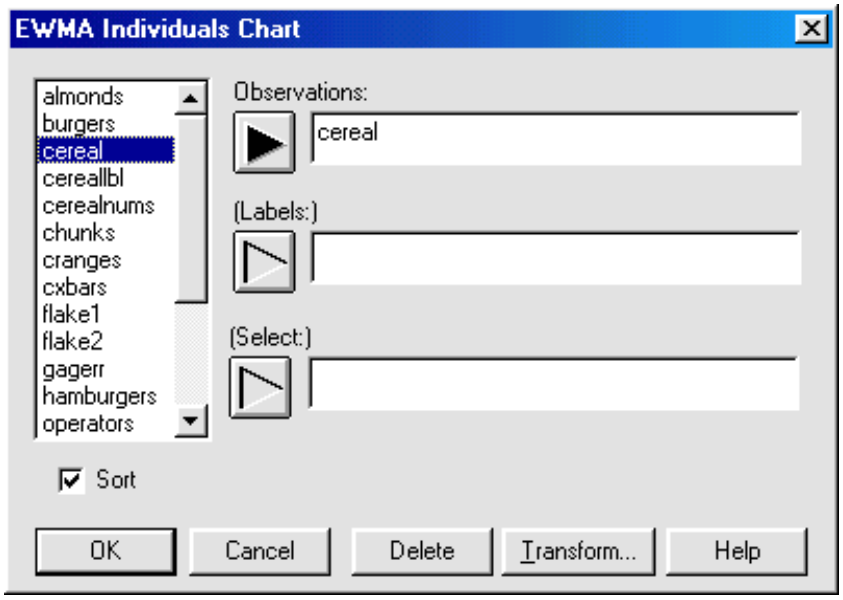


Figure 5-40. EWMA Individuals Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 5-41). The program constructs the control charts under the assumption that the data come from a normal distribution with values for the mean and standard deviation, which are estimated from the data. However, the EWMA is insensitive to this assumption.

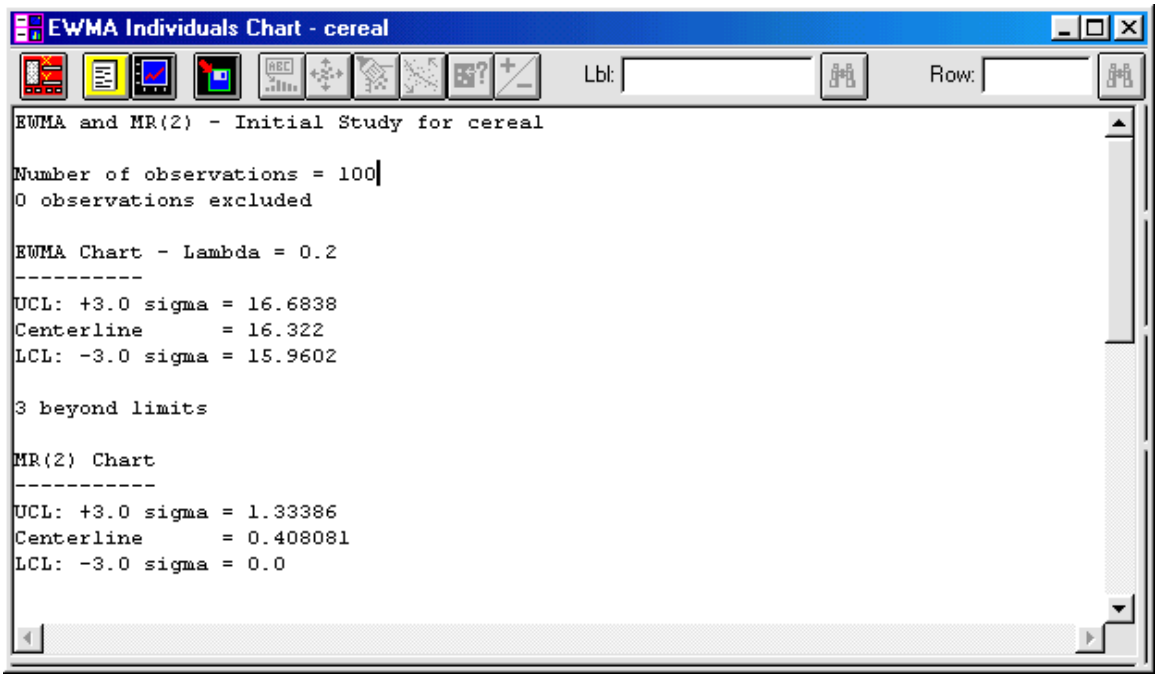


Figure 5-41. Analysis Summary

For the EWMA Chart and the MR(2) Chart, the report displays the values for the upper and lower control limits, the centerline, and the number of observations beyond the limits. The report also shows the number of observations, and the number of observations excluded from the study. It provides estimates for the process mean, process sigma, and Mean MR(2). For a control-to-standard study, the report includes the standard statistics.

Use the *EWMA Individuals Chart Options* dialog box to indicate if the study will be an initial or a control to standard; to enter a number that will be used as the weighting factor that will be applied to each new observation to calculate the exponentially weighted moving average; to enter a number that will be used to calculate the average run length; and to indicate the location of the EWMA and the MR(2) control limits and the numbers that will be used to calculate them (see Figure 5-42). For a control-to-standard study, you can specify the values that will be used for the mean and sigma parameters. This dialog box is available from all the tabular and graphical panes so you can make changes that will affect the analysis.

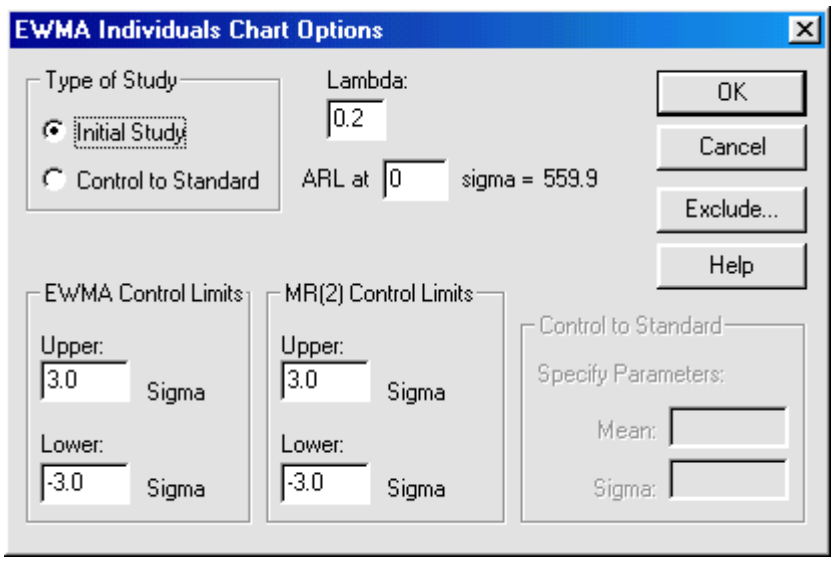


Figure 5-42. EWMA Individuals Chart Options Dialog Box

EWMA Individuals Chart Report

The EWMA Individuals Chart Report option creates a report of the observations based on your selection on the EWMA Individuals Chart Report Options dialog box (see Figure 5-43). The report shows the observation number, and values for the EWMA and MR(2). It notes points that are beyond the control limits with an asterisk, and points that are excluded with an X. You can create a report that displays all the observations; observations beyond the control limits, EWMA beyond the limits, MR(2) beyond the limits, or observations that were excluded.

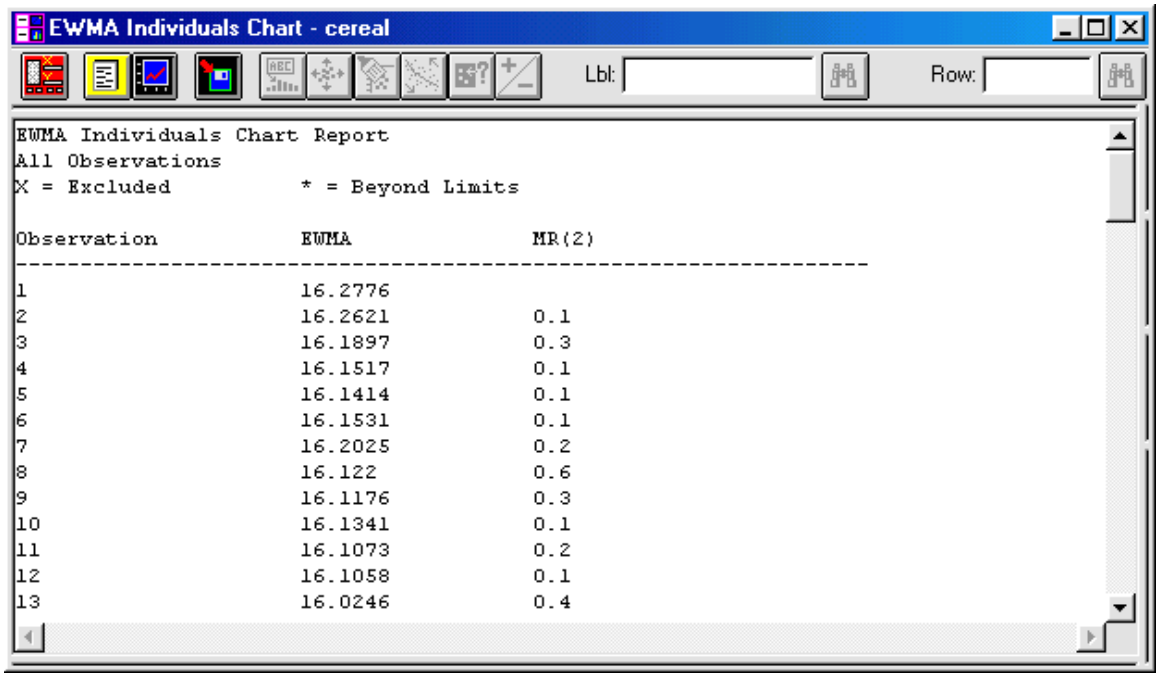


Figure 5-43. EWMA Individuals Chart Report

Use the *EWMA Individuals Chart Report Options* dialog box to choose the report you want to create (see Figure 5-44).

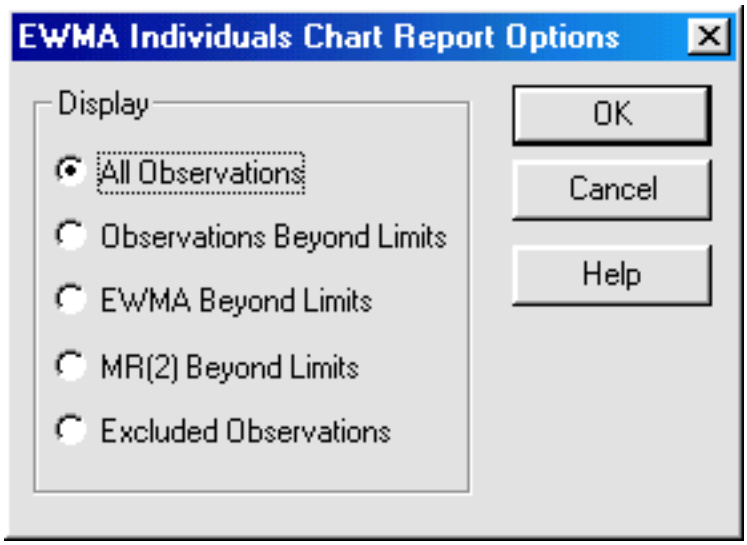


Figure 5-44. EWMA Individuals Chart Report Options Dialog Box

Capability Indices

The Capability Indices option calculates several process capability indices based on the estimated process mean and standard deviation (see Figure 5-45). The indices help determine the capability of the process to produce products that meet a quality standard.

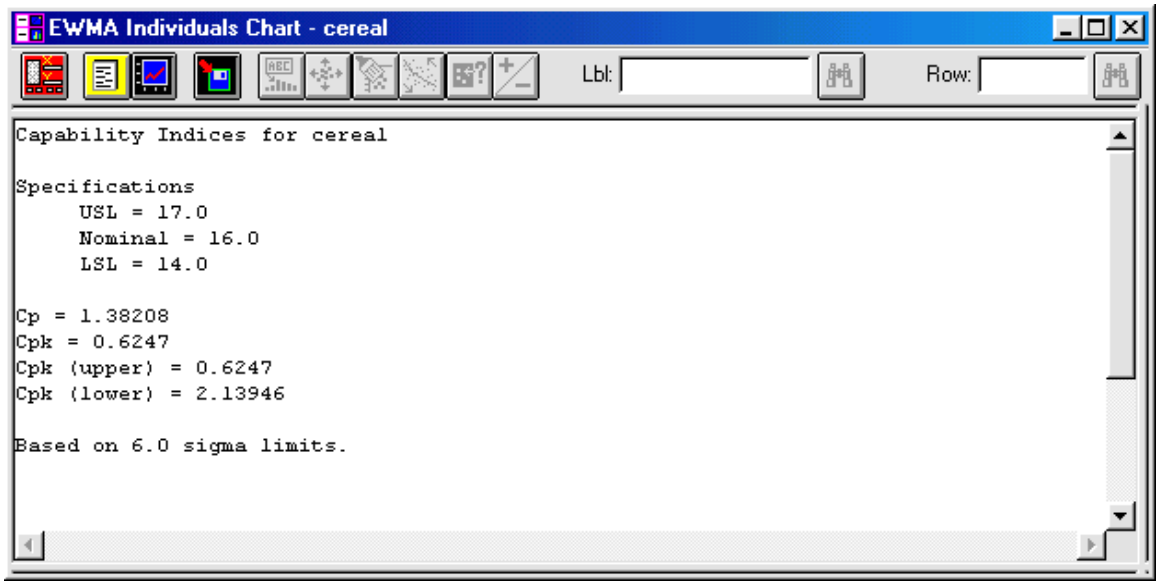


Figure 5-45. Capability Indices

Use the *Process Capability Indices Options* dialog box to choose the indices you want to include in the report, and to enter values for the upper and lower specification limits and the nominal (see Figure 5-46).

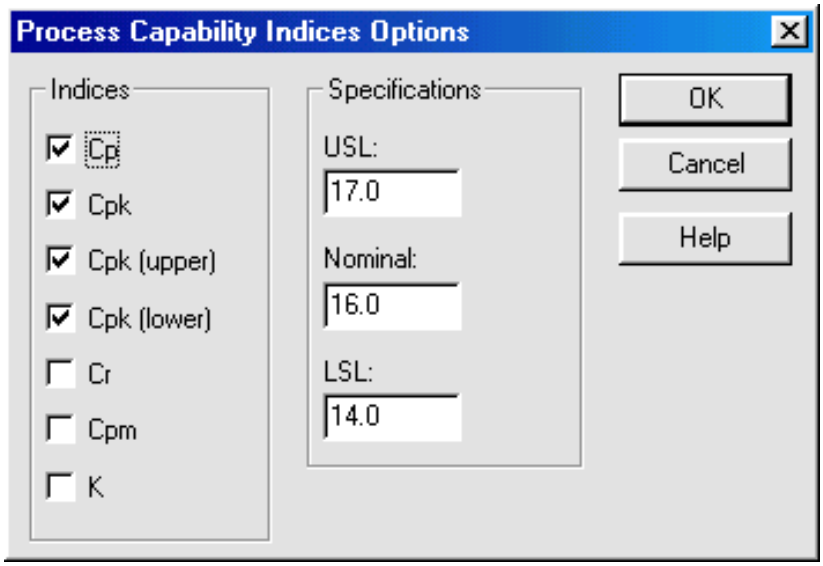


Figure 5-46. Process Capability Indices Options Dialog Box

Graphical Options

EWMA Chart

The EWMA Chart option creates a plot of the exponentially weighted moving averagaes for each of the measurements (see Figure 5-47). The chart identifies points beyond the control limits.

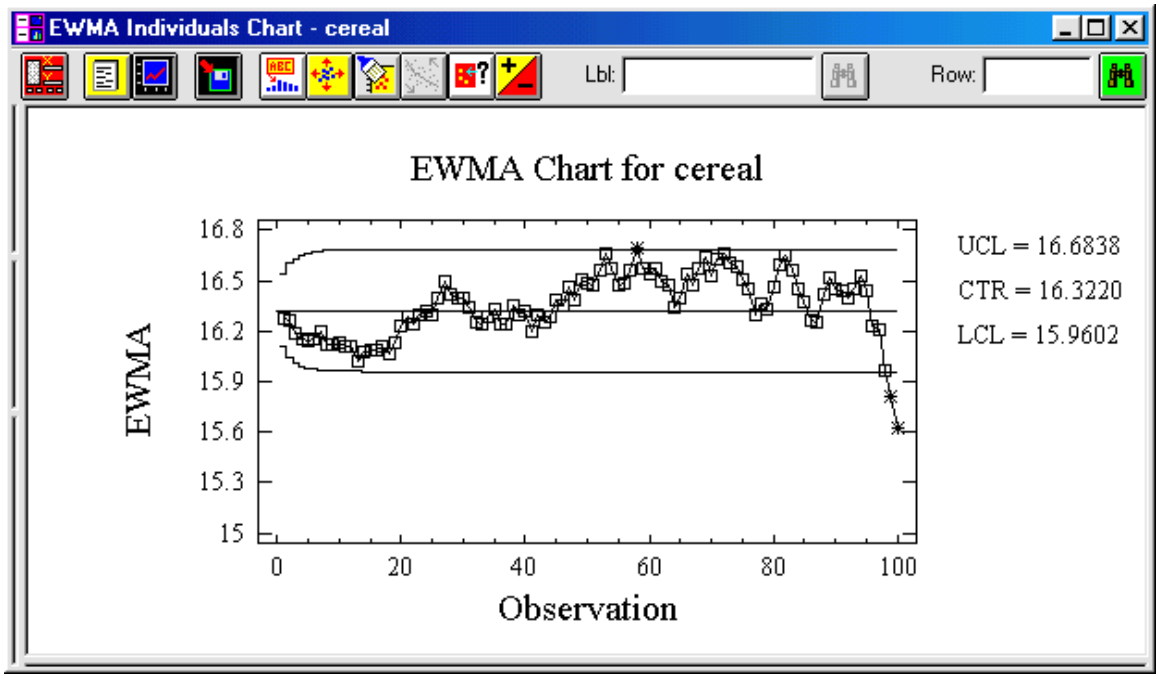


Figure 5-47. EWMA Chart

Use the *EWMA Chart Options* dialog box to indicate if you want to plot the original data, and to enter the number of decimal places that will be used for displaying the limits (see Figure 5-48).

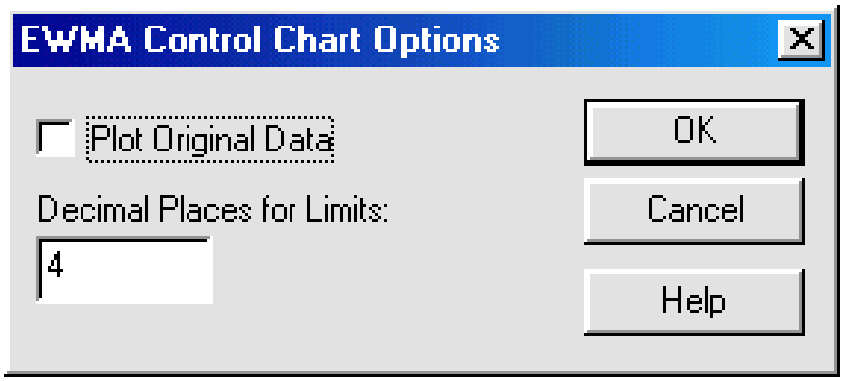


Figure 5-48. EWMA Chart Options Dialog Box

MR(2) Chart

The MR(2) Chart option creates a plot of the moving ranges for each of the measurements (see Figure 5-49). It identifies the points that are beyond the control limits.

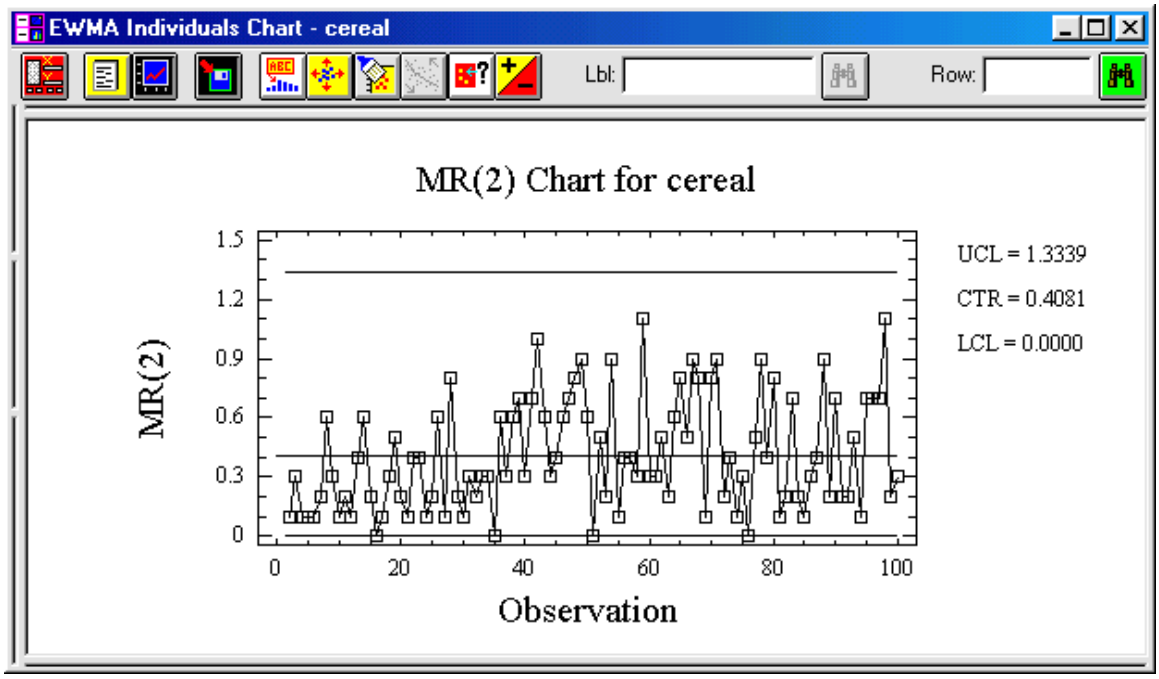


Figure 5-49. MR(2) Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; to indicate if you want the simple moving average of the subgroup statistics superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the subgroup statistics superimposed on the chart, and if so, to enter a value for lambda; and to enter the number of decimal places that will be used for displaying the limits. *See Figure 5-11 for an example of this dialog box.*

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point plotted on the control chart will remain inside the control limits as a function of the true process mean (see Figure 5-50). In other words, it plots the probability that there will not be a signal from the chart, even though the process is not at the assumed center. The results are useful when you need to determine the effectiveness of the control chart in detecting drifts in the process away from the target. The X-axis shows the shift in the average; the Y-axis shows the probability of not detecting the shift.

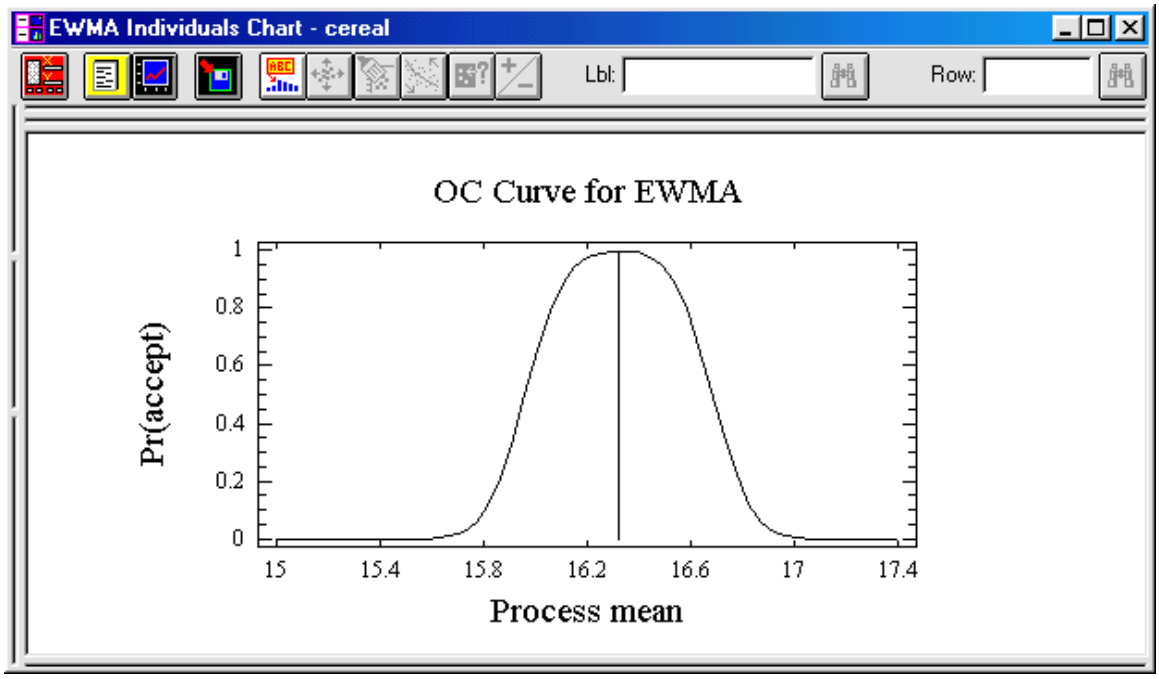


Figure 5-50. OC Curve

ARL Curve

The ARL (Average Run Length) Curve option creates a plot that shows the ARL for the EWMA Chart as a function of the process mean (see Figure 5-51). For example, if the process is actually running at the centerline, the chart will not create an out-of-control signal on average for several samples. If the process moves away from the centerline, the ARL will change accordingly. The plot is helpful when you need to select an adequate sampling plan to monitor the process.

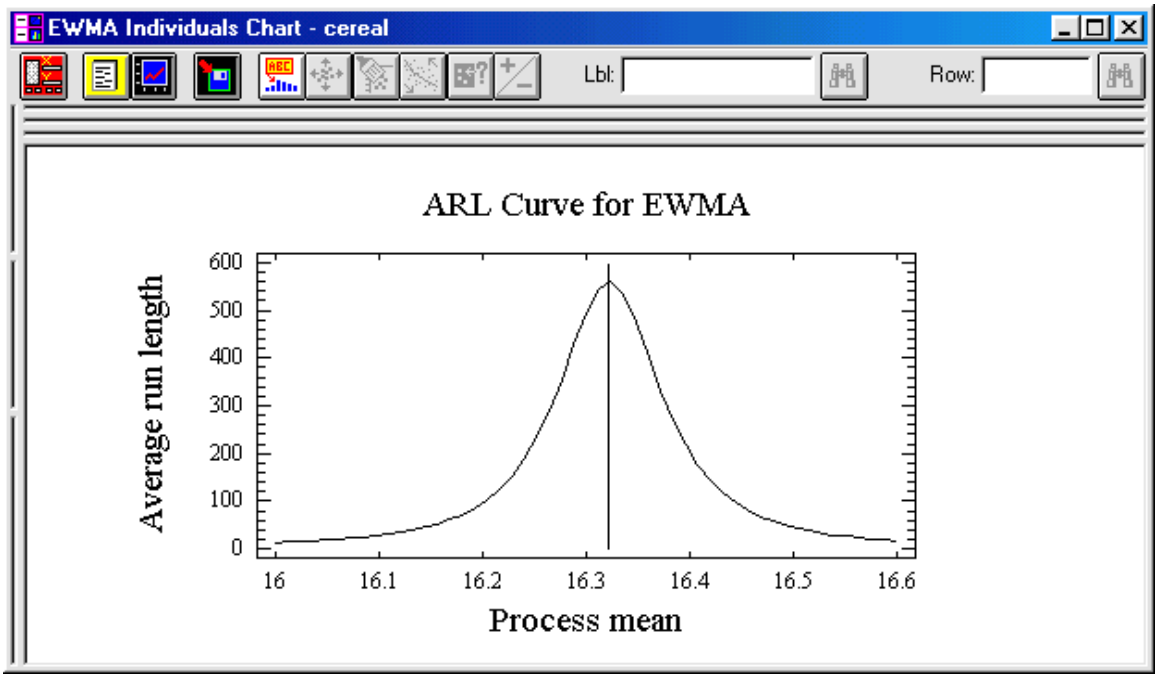


Figure 5-51. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are six selections: EWMAs, Moving Ranges, Labels, Process Mean, Process Sigma, and Included Observations.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the CuSum Chart (V-Mask) Analysis

The CuSum or Cumulative Sum Charts are generally used for detecting small shifts in the process mean -- detecting .5 sigma to 2 sigmas -- in about half the time of Shewhart charts with the same sample size (Montgomery, 1991). An inflection in the plotted points makes the point at which the shift occurs easy to detect. For large shifts in the process mean, these charts are slower in detecting the shift.

The time-weighted chart is based on all the data instead of only the last few samples. The cumulative sums for the deviations of the sample values from the target value are plotted.

The analysis helps to maintain current control of a process. An upward or downward trend in the data indicates that the process mean has shifted and the process is out of control. The analysis also helps detect sudden and persistent changes in the process average more rapidly than variables control charts do. By detecting the change in the process sooner, you can adjust the process before large variations occur.

To Access the CuSum Chart (V-Mask) Analysis

1. Choose SPECIAL... QUALITY CONTROL... TIME-WEIGHTED CHARTS... CUSUM CHART (V-MASK)... from the Menu bar to display the Analysis dialog box shown in Figure 5-52.

2. Complete the dialog box and click OK to display the Analysis Summary and the CuSum Chart in the Analysis window.

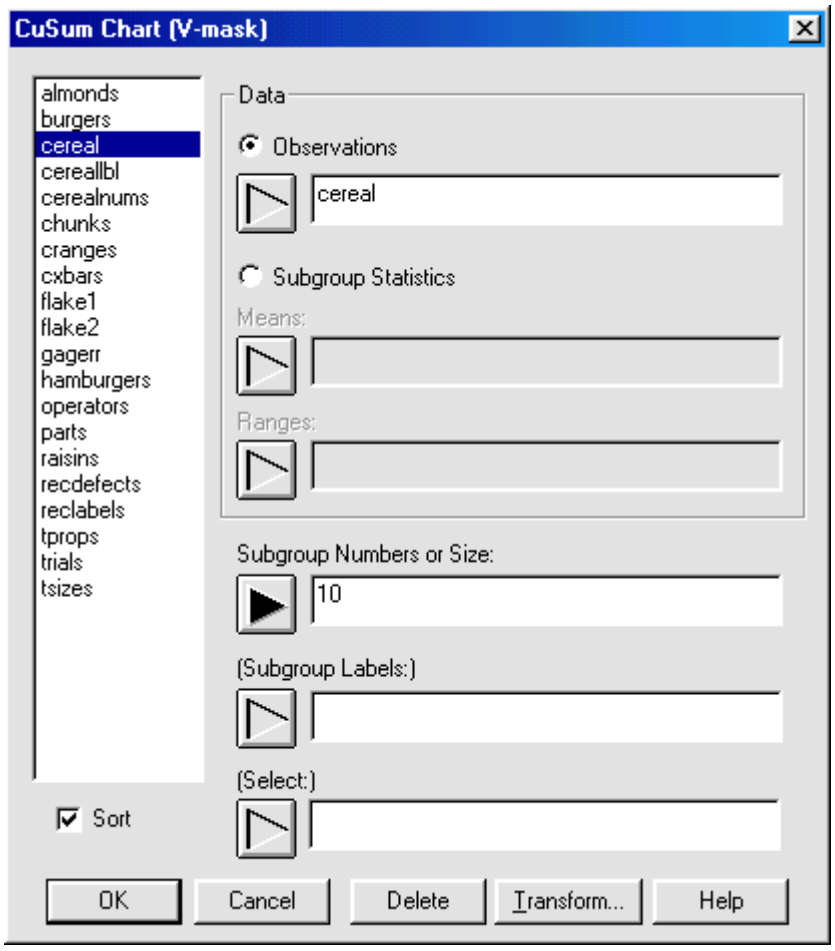


Figure 5-52. CuSum Chart (V-Mask) Analysis Dialog Box

Tabular Options

Analysis Summary
The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 5-53). The program constructs the control charts under the assumption that the data come from a normal distribution with values for the mean and standard deviation, which are estimated from the data.

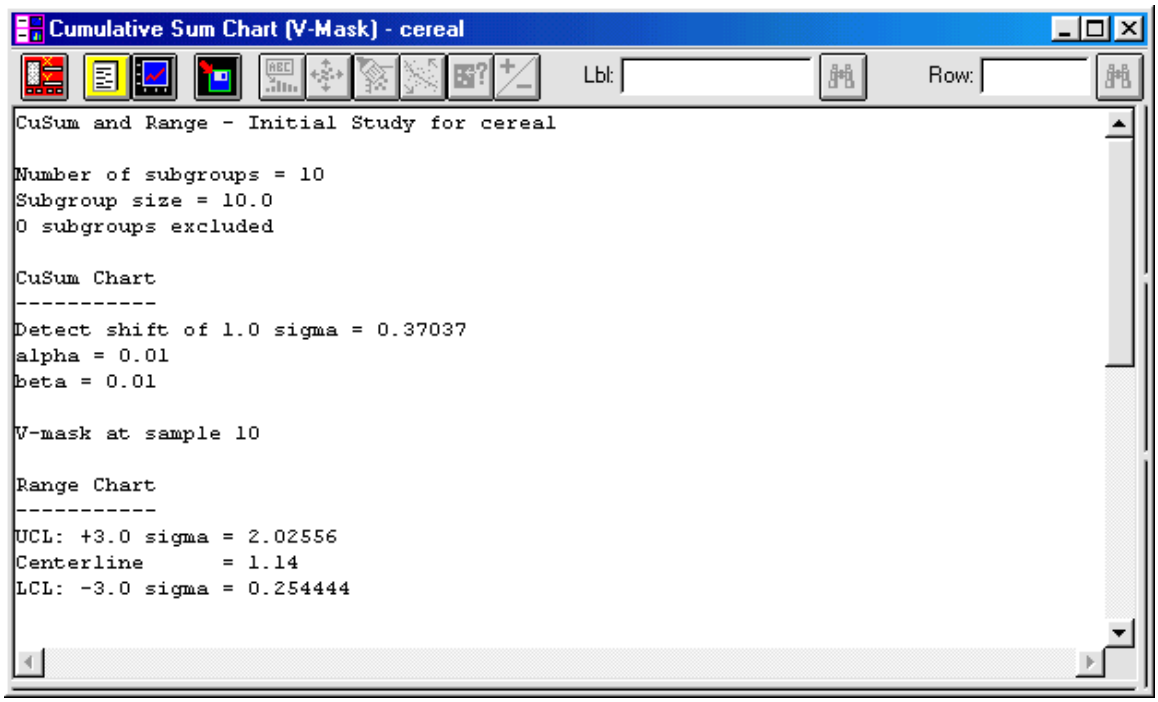


Figure 5-53. Analysis Summary

For the CuSum Chart, the report displays the number of standard deviations from the control mean at which a shift in the process is detected, the values for alpha and beta that represent the risk of a Type I or Type II error occurring, and the sample number at which the V-mask is placed on the Chart. For the Range Chart, the report displays the values for the upper and lower control limits, the centerline, and the number of subgroups beyond the limits. The report also shows the number of subgroups, the subgroup size, and the number of subgroups excluded from the study. It provides estimates for the process mean, process sigma, and the mean range. For a control-to-standard study, the report includes the standard statistics.

Use the *CuSum Chart Options* dialog box to indicate if the study will be an initial or a control to standard; to enter the number of standard deviations from the control mean at which you want a shift detected; to enter the subgroup number at which the V-mask will be placed on the chart; to enter a value for alpha (Type I) and beta (Type II) error for the CuSum Chart; and to enter values for sigma for the upper and

lower control limits for the Range Chart (see Figure 5-54). For a control-to-standard study, you can specify the values that will be used for the mean and sigma parameters. This dialog box is available from all the tabular and graphical panes so you can make changes that will affect the analysis.

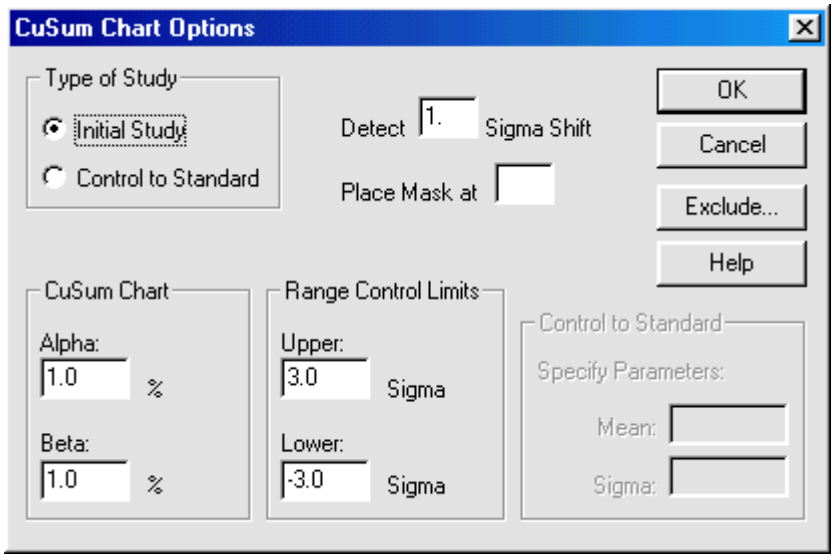


Figure 5-54. CuSum Chart Options Dialog Box

CuSum Chart Report

The CuSum Chart Report option creates a report of the subgroups based on your selection on the CuSum Chart Report Options dialog box (see Figure 5-55). The report shows the values that are plotted on the control chart, including values for the size, CuSum value, and range. It notes points that are beyond the control limits with an asterisk, and points that are excluded with an X. You can create a report that displays all the subgroups; subgroups beyond the control limits, CuSum values beyond the limits, ranges beyond the limits, or subgroups that were excluded.

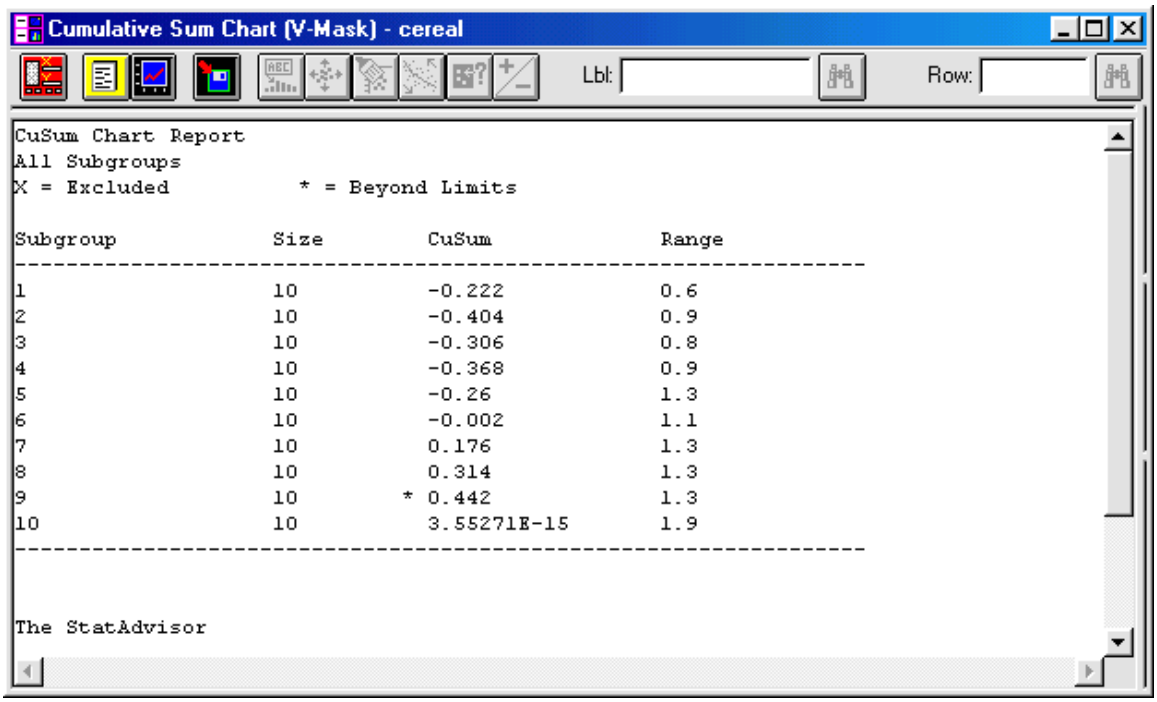


Figure 5-55. CuSum Chart Report

Use the *CuSum Chart Report Options* dialog box to choose the report you want to create, and to enter the number of decimal places that will be used for displaying the limits (see Figure 5-56).

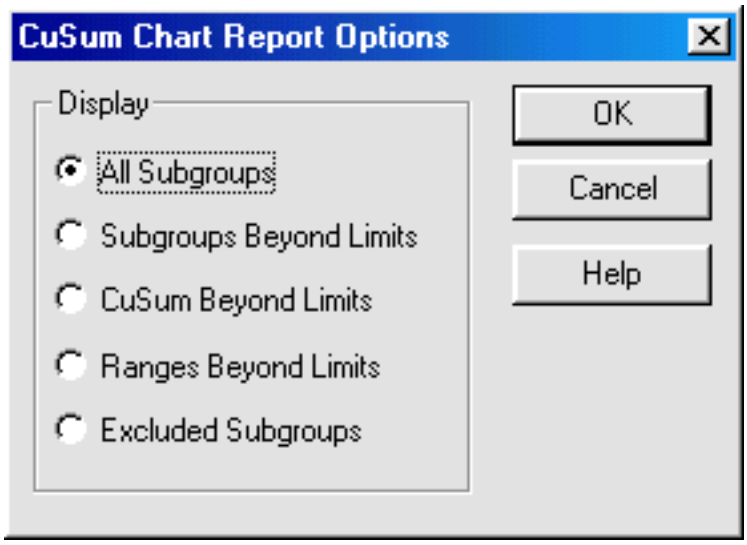


Figure 5-56. CuSum Chart Report Options Dialog Box

Graphical Options

Cumulative Sum Chart

The Cumulative Sum Chart option creates a plot of the cumulative sum of the deviations from target for each of the subgroups (see Figure 5-57). A V-mask placed in front of the most recent point determines if the process is in statistical control. If the process is in control, all of the points should be within the mask.

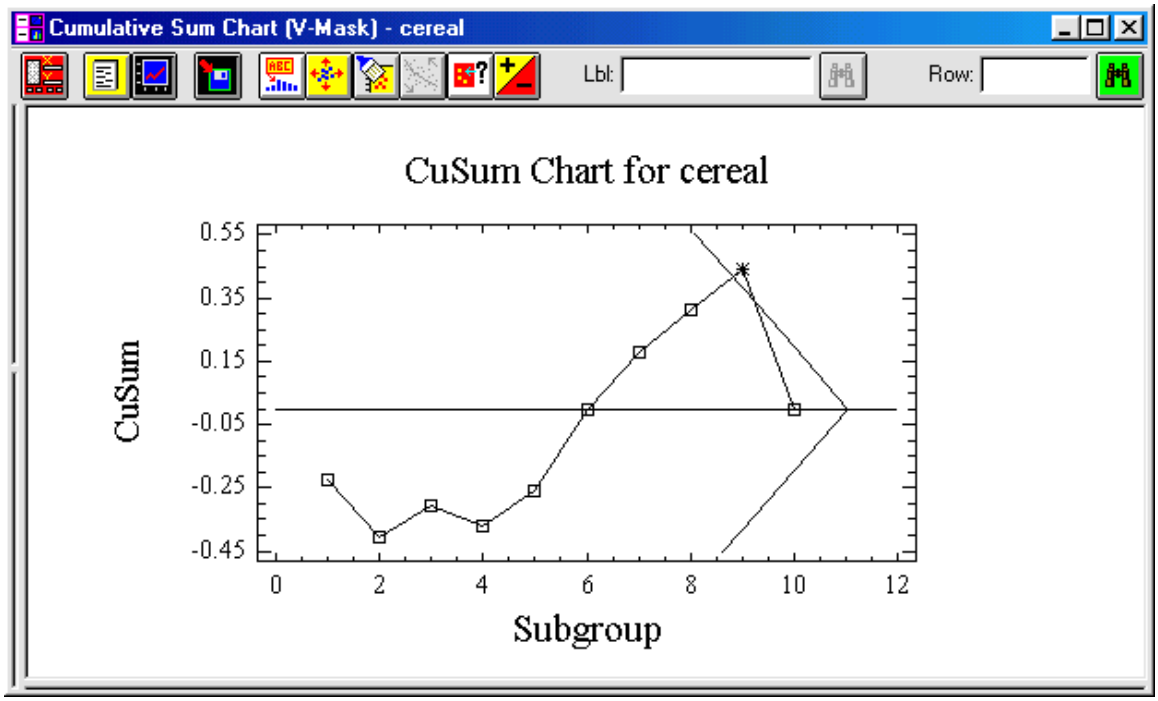


Figure 5-57. Cumulative Sum Chart

Range Chart

The Range Chart option creates a plot of the ranges for each of the subgroups, and shows the points that are beyond the control limits (see Figure 5-58).

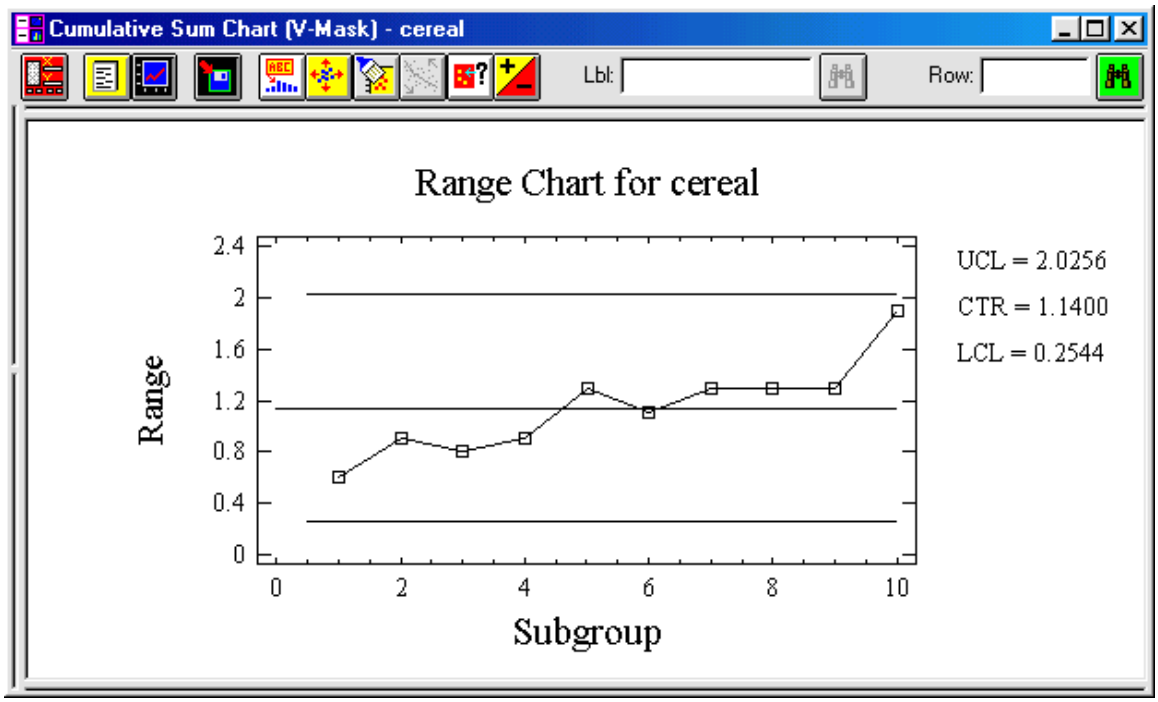


Figure 5-58. Range Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; to indicate if you want the simple moving average of the subgroup statistics superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the subgroup statistics superimposed on the chart, and if so, to enter a value for lambda; and to enter the number of decimal places that will be used for displaying the limits. *See Figure 5-11 for an example of this dialog box.*

ARL Curve

The ARL (Average Run Length) Curve option creates a plot that shows the ARL for the CuSum Chart as a function of the process mean (see Figure 5-59). For example, if the process is actually running at the centerline, the chart will not create an out-of-control signal on average for several samples. If the process moves away from the centerline, the ARL will change accordingly. The plot is helpful when you need to select an adequate sampling plan to monitor the process.

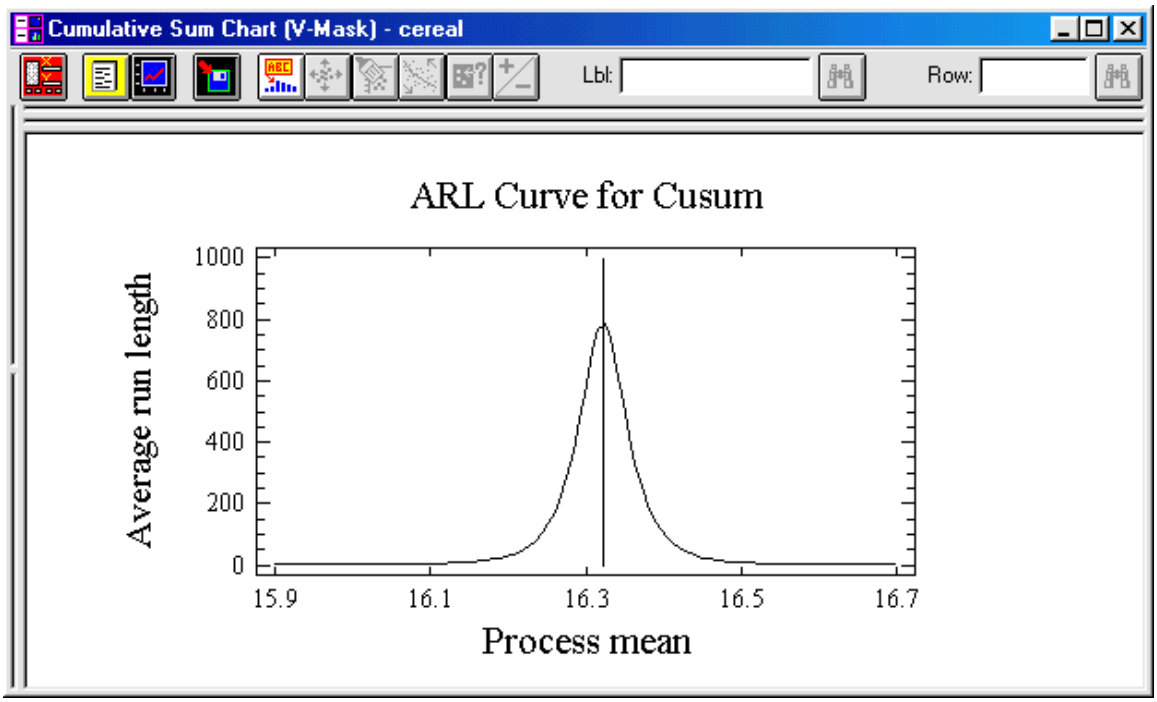


Figure 5-59. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are six selections: Cumulative Sum, Ranges, Sizes, Labels, Process Mean, and Process Sigma.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the CuSum Individuals Chart (V-Mask) Analysis

The CuSum or Cumulative Sum Charts are generally used for detecting small shifts in the process mean -- detecting .5 sigma to 2 sigmas -- in about half the time of Shewhart charts with the same sample size (Montgomery, 1991). An inflection in the plotted points makes the point at which the shift occurs easy to detect. For large shifts in the process mean, these charts are slower in detecting the shift.

The time-weighted chart is based on all the data instead of only the last few samples. The cumulative sums for the deviations of the sample values from the target value are plotted.

The CuSum Individuals Chart Analysis produces a time-weighted chart of the individual observations. This analysis plots the cumulative sums of the deviations of the sample from the target value. Use this analysis when the subgroup size is 1.

You can use the analysis to maintain current control of a process. An upward or downward trend in the data indicates that the process mean has shifted and the process is out of control. The CuSum Individuals Chart allows you to detect sudden and persistent change in the process average more rapidly than variables controls charts. By detecting the changes sooner, you can adjust the process before large variations occur. This analysis is particularly useful in chemical and process industries where individual items may be difficult to form into subgroups.

To Access the CuSum Individuals Chart (V-Mask) Analysis

1. Choose SPECIAL... QUALITY CONTROL... TIME-WEIGHTED CHARTS... CUSUM INDIVIDUALS CHART (V-MASK)... from the Menu bar to display the Analysis dialog box shown in Figure 5-60.

2. Complete the dialog box and click OK to display the Analysis Summary and the CuSum Individuals Chart in the Analysis window.

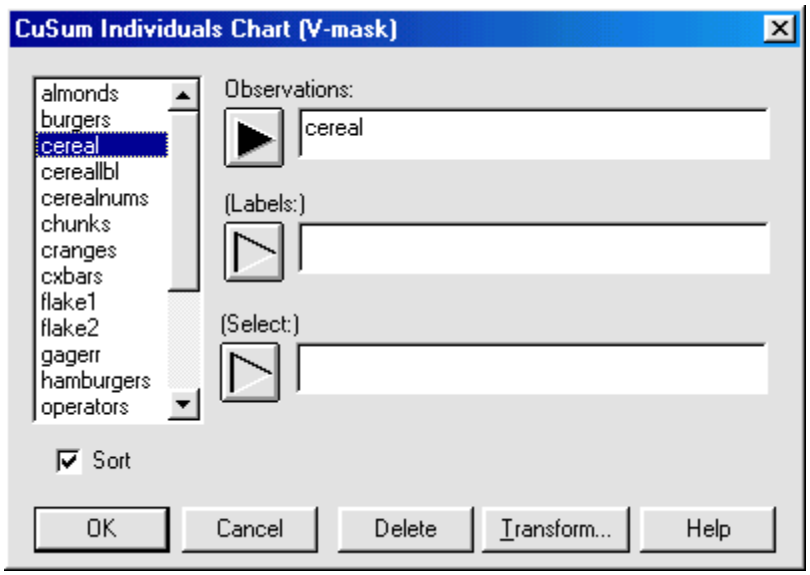


Figure 5-60. CuSum Individuals Chart (V-Mask) Analysis Dialog Box

Tabular Options

Analysis Summary
The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 5-61). The program constructs the control charts under the assumption that the data come from a normal distribution with values for the mean and standard deviation, which are estimated from the data.

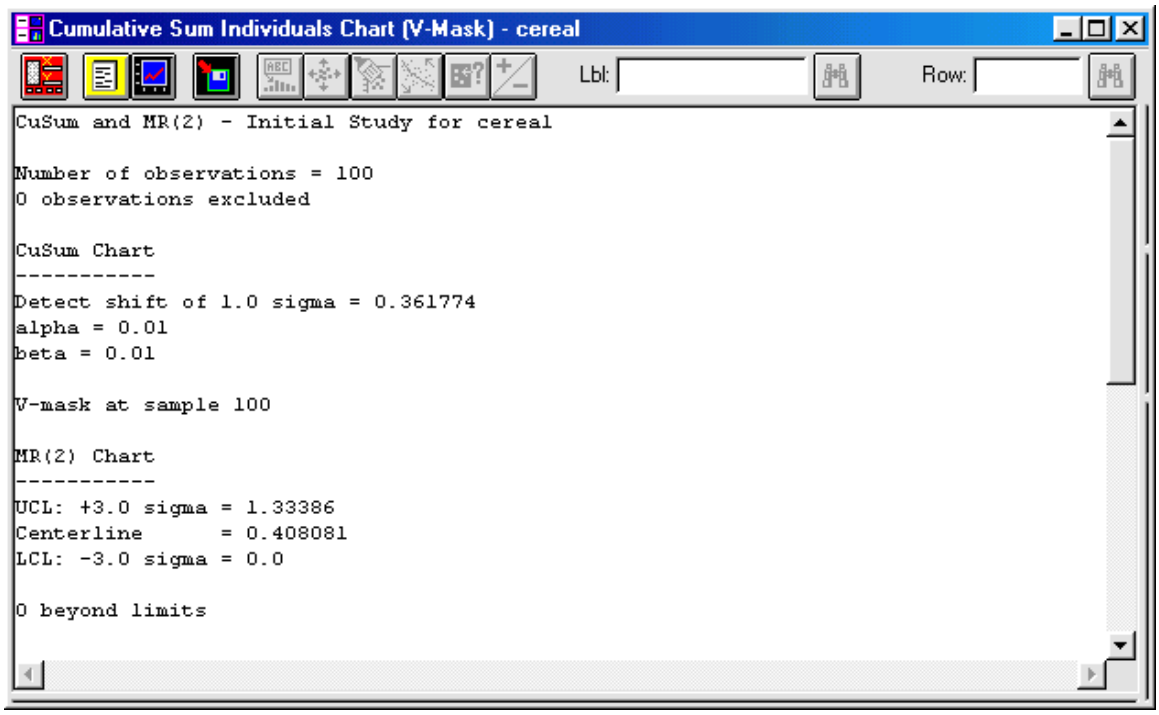


Figure 5-61. Analysis Summary

For the CuSum Chart, the report displays the number of standard deviations from the control mean at which a shift in the process is detected, the values for alpha and beta that represent the risk of a Type I or Type II error occurring, and the sample number at which the V-mask is placed on the Chart. For the MR(2) Chart, the report displays the values for the upper and lower control limits, the centerline, and the number of observations beyond the limits. The report also shows the number of observations, and the number of observations excluded from the study. It provides estimates for the process mean, process sigma, and the mean MR(2). For a control-to-standard study, the report includes standard statistics.

Use the *CuSum Individuals Chart Options* dialog box to indicate if the study will be an initial or a control to standard; to enter the number of standard deviations from the control mean at which you want a shift detected; to enter the subgroup number at which the V-mask will be placed on the chart; to enter a value for alpha (Type I)

and beta (Type II) error for the CuSum Chart; and to enter values for sigma for the upper and lower control limits for the MR(2) Chart (see Figure 5-62). For a control-to-standard study, you can specify the values that will be used for the mean and sigma parameters. This dialog box is available from all the tabular and graphical panes so you can make changes that will affect the analysis.

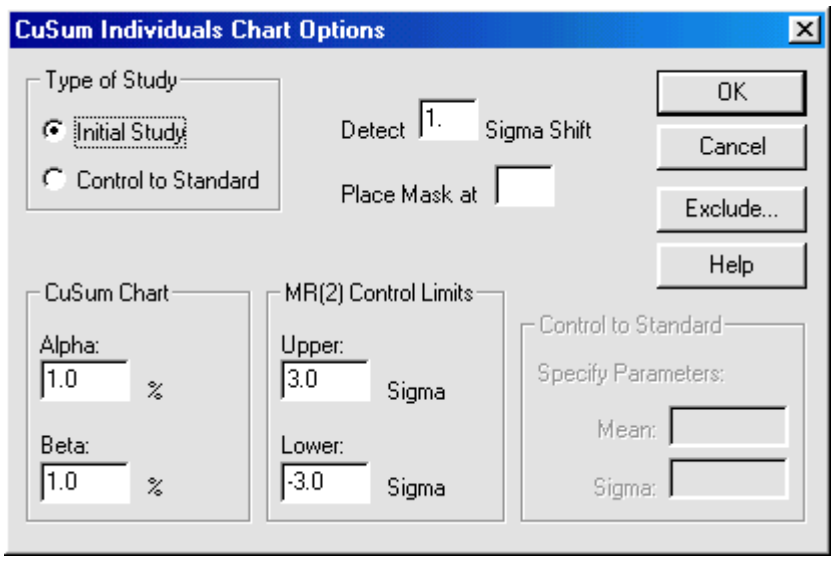


Figure 5-62. CuSum Individuals Chart Options Dialog Box

CuSum Individuals Chart Report

The CuSum Individuals Chart Report option creates a report of the observations based on your selection on the CuSum Individuals Chart Report Options dialog box (see Figure 5-63). The report shows the values that are plotted on the control chart, including values for the CuSum and MR(2). It notes points that are beyond the control limits with an asterisk, and points that are excluded with an X. You can create a report that displays all the observations; observations beyond the control limits, CuSum values beyond the limits, MR(2) values beyond the limits, or observations that were excluded.

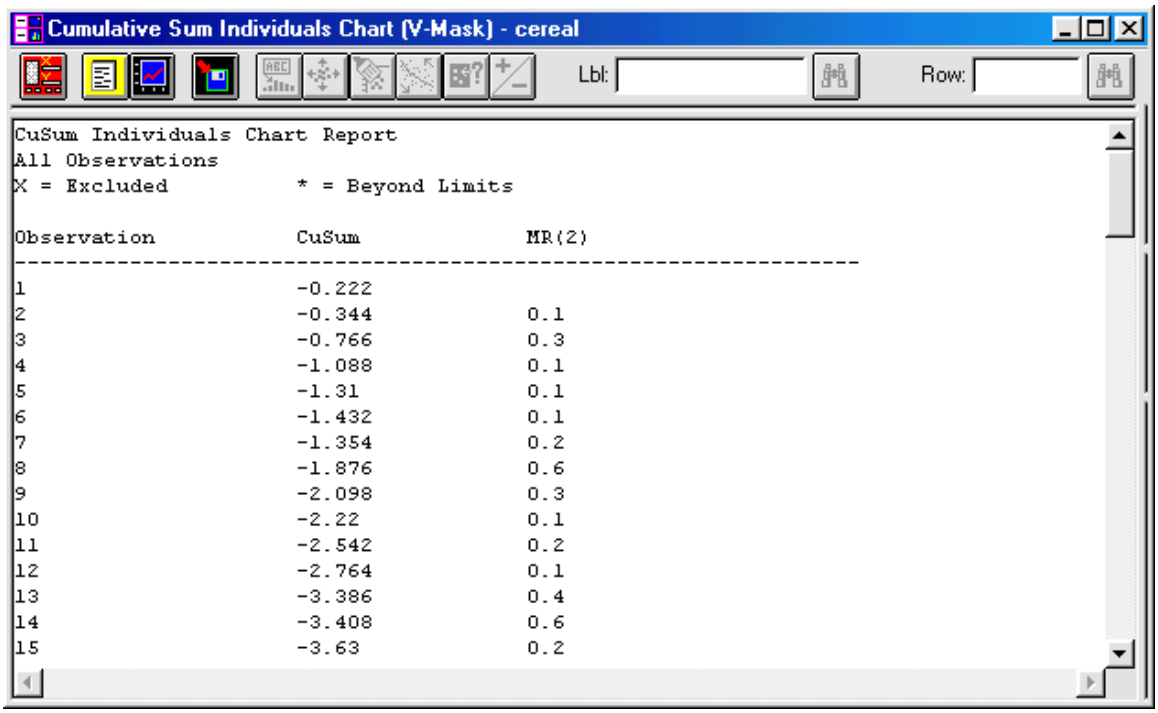


Figure 5-63. CuSum Individuals Chart Report

Use the *CuSum Individuals Chart Report Options* dialog box to choose the report you want to create, and to enter the number of decimal places that will be used for displaying the limits (see Figure 5-64).

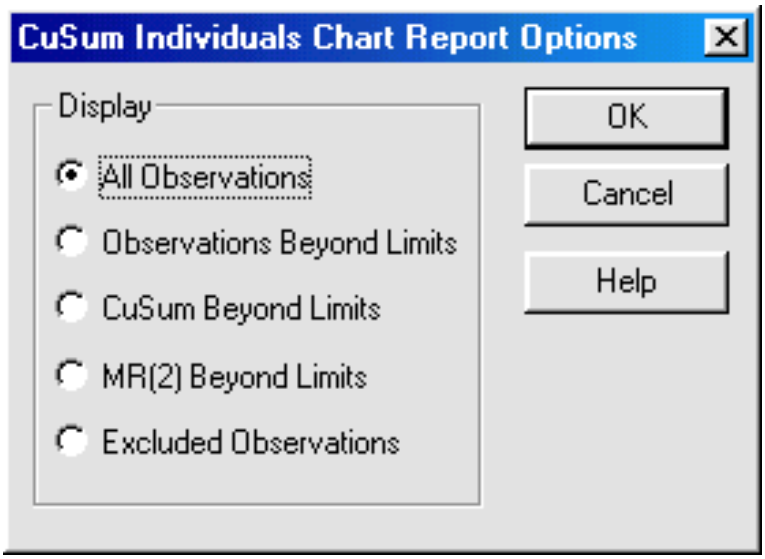


Figure 5-64. CuSum Individuals Chart Report Options Dialog Box

Graphical Options

Cumulative Sum Chart

The Cumulative Sum Chart option creates a plot of the cumulative sum of the deviations from target for each of the measurements (see Figure 5-65). A V-mask placed in front of the most recent point determines if the process in statistical control. If the process is in control, all of the points should be within the mask.

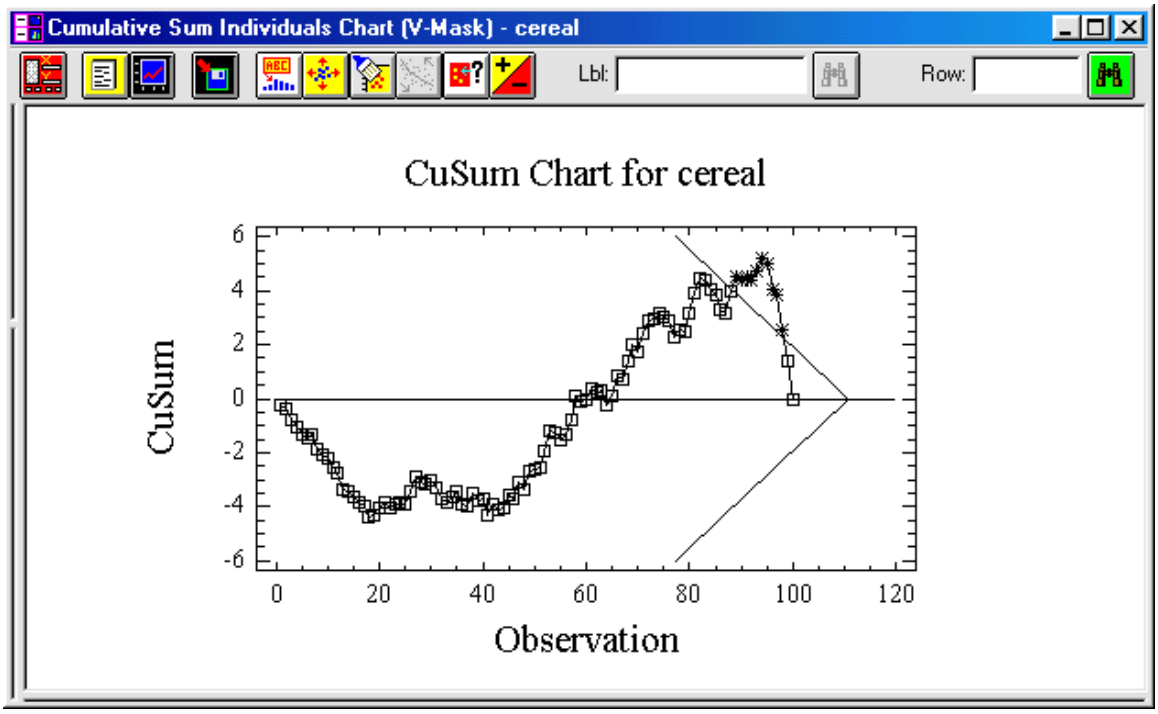


Figure 5-65. Cumulative Sum Chart

MR(2) Chart

The MR(2) Chart option creates a plot of the moving ranges for each of the measurements (see Figure 5-66). It notes the points that are beyond the control limits.

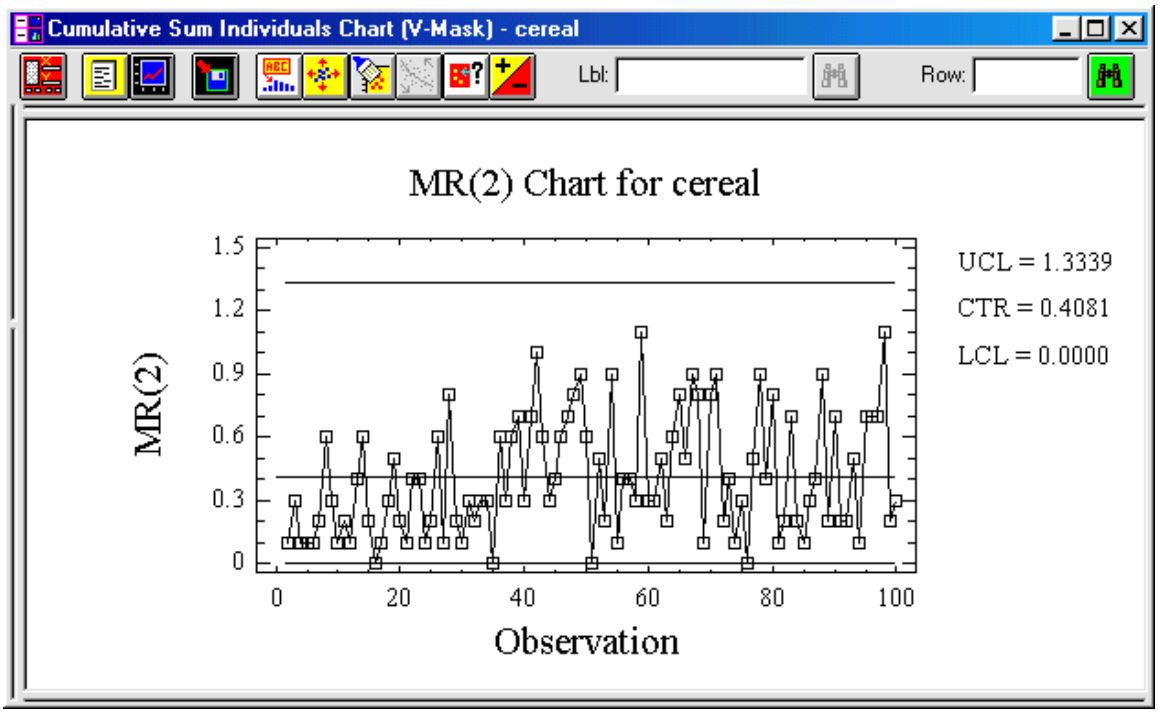


Figure 5-66. MR(2) Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; to indicate if you want the simple moving average of the subgroup statistics superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the subgroup statistics superimposed on the chart, and if so, to enter a value for lambda; and to enter the number of decimal places that will be used for displaying the limits. *See Figure 5-11 for an example of this dialog box.*

ARL Curve

The ARL (Average Run Length) Curve option creates a plot that shows the ARL for the CuSum Chart as a function of the process mean (see Figure 5-67). For example, if the process is actually running at the centerline, the chart will not create an out-of-control signal on average for several samples. If the process moves away from the centerline, the ARL will change accordingly. The plot is helpful when you need to select an adequate sampling plan to monitor the process.

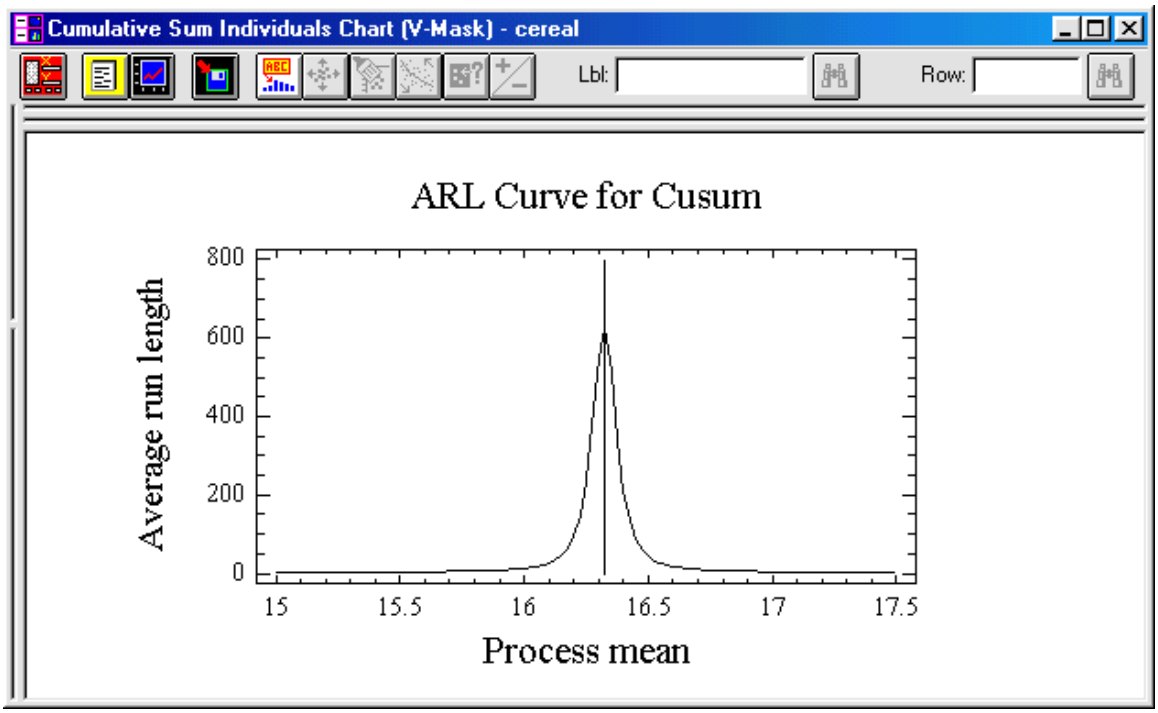


Figure 5-67. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are six selections: Cumulative Sum, Moving Ranges, Labels, Process Mean, Process Sigma, Included Observations.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the CuSum Chart (H-K) Analysis

The CuSum Chart (H-K) Analysis is also called the *algorithmic* or *tabular* CuSum. The technique accumulates deviations above the target separately from deviations below the target. Those accumulated deviations above the target become the one-sided upper CuSums. The accumulated deviations below the target become the one-sided lower CuSums. The process is determined to be out of control when either type of CuSum exceeds the decision interval, called H.

To Access the CuSum Chart (H-K) Analysis

1. Choose SPECIAL... QUALITY CONTROL... TIME-WEIGHTED CHARTS... CUSUM CHART (H-K)... from the Menu bar to display the Analysis dialog box shown in Figure 5-68.

2. Complete the dialog box and click OK to display the Analysis Summary and the CuSum Chart in the Analysis window.

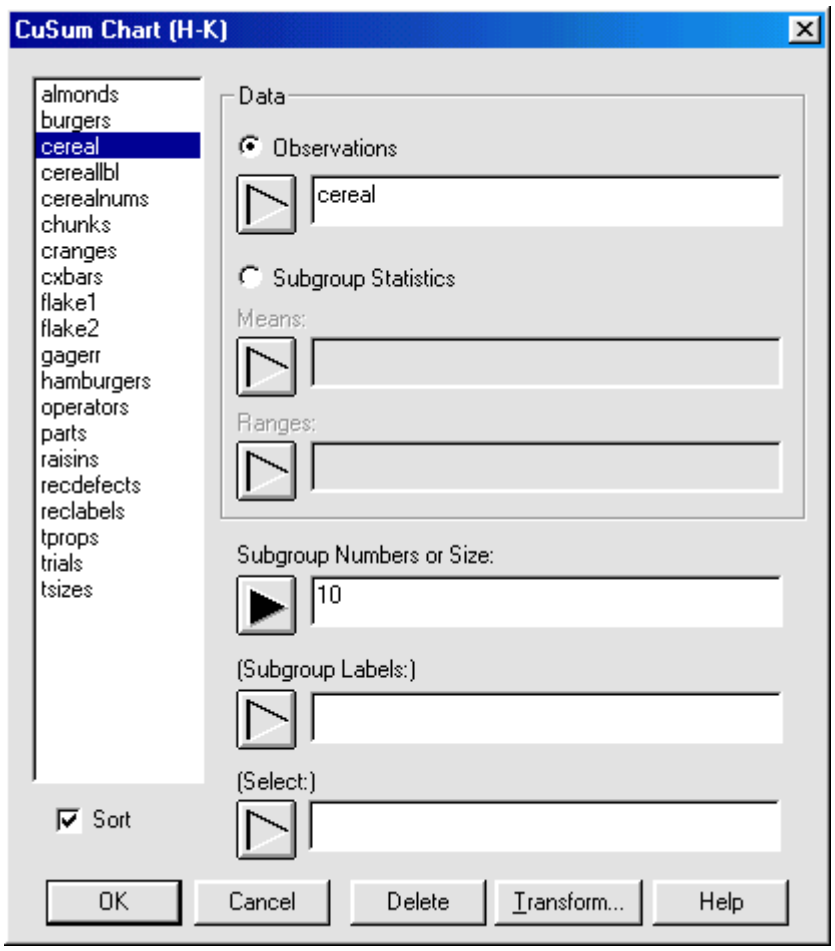


Figure 5-68. CuSum (H-K) Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 5-69). The program constructs the control charts under the assumption that the data come from a normal distribution

with values for the mean and standard deviation, which are estimated from the data.

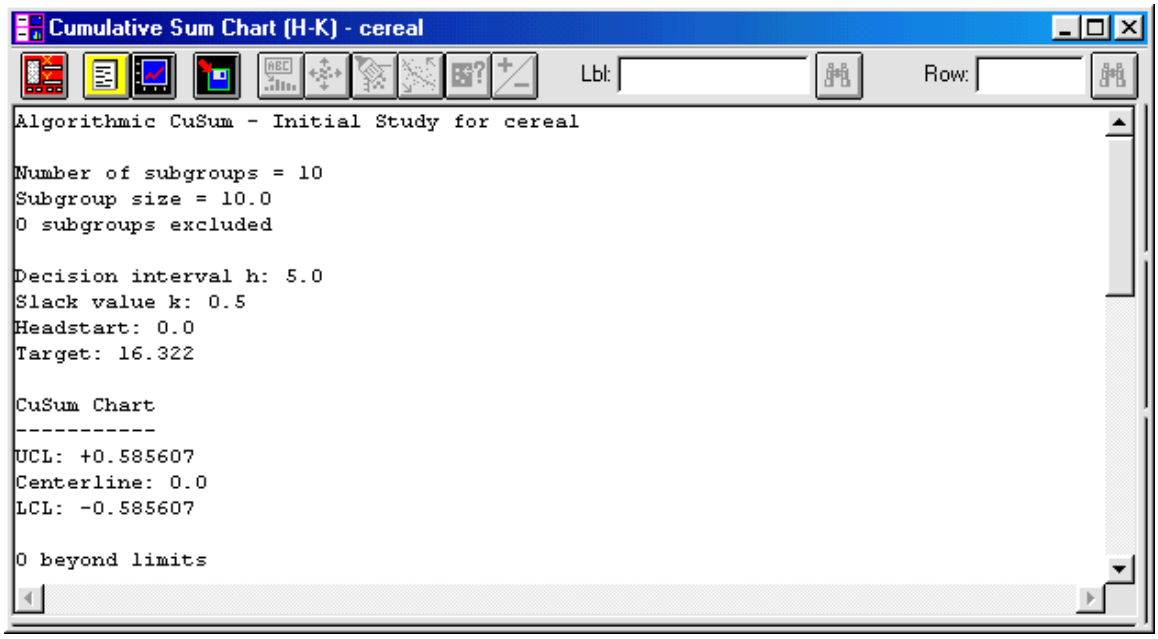


Figure 5-69. Analysis Summary

For the CuSum Chart and the Range Chart, the report displays the values for the upper and lower control limits, the centerline, and the number of subgroups beyond the limits. The report also shows the number of subgroups, the subgroup size, and the number of subgroups excluded from the study. It provides estimates for the process mean, process sigma, and mean range. For a control-to-standard study, the report includes the standard statistics.

Use the *CuSum (H-K) Chart Options* dialog box to indicate if the study will be an initial or a control to standard; to enter a value for sigma for the decision interval (H); to enter a value for sigma for the reference value (K); to enter a number that will be used to calculate the average run length (ARL); to enter a number that will shift the initial values of the upper and lower CuSums; to indicate if the CuSum control limits will be two-sided, upper only, or lower only; and if the data should be normalized; and to enter values for sigma for the upper and lower Range control limits (see Figure 5-70). For a control-to-standard study, you can specify the values that will be used for the mean and sigma parameters. This dialog box is available from all the tabular and graphical panes so you can make changes that will affect the analysis.

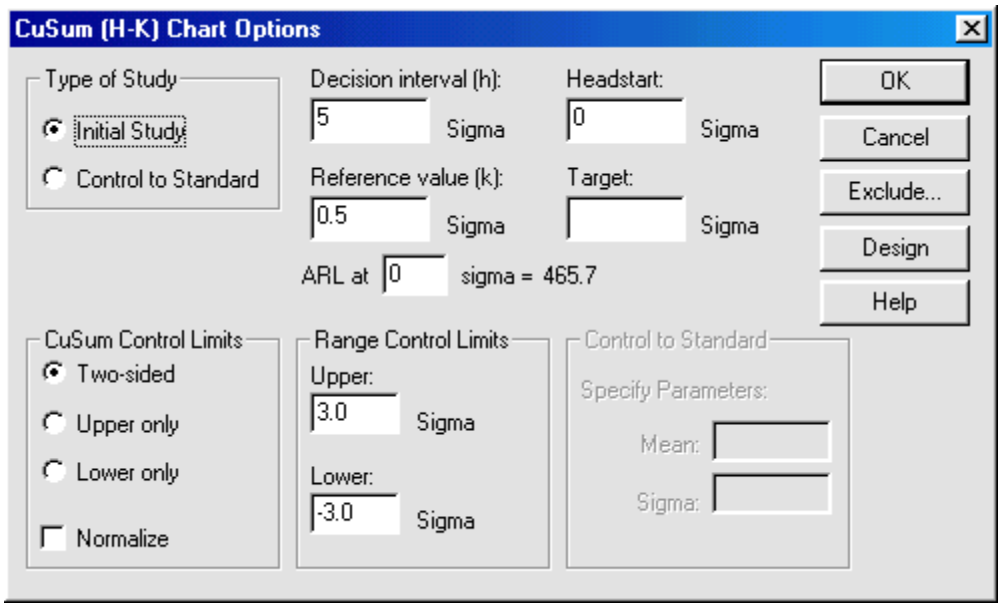
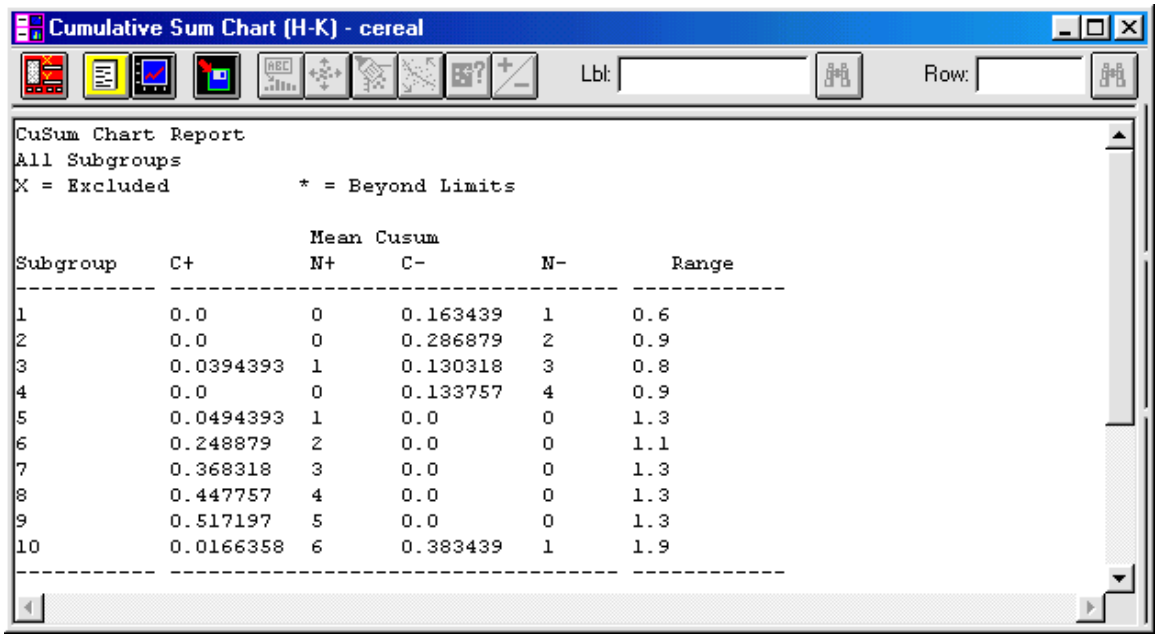


Figure 5-70. CuSum (H-K) Chart Options Dialog Box

CuSum Chart Report

The CuSum Chart Report option creates a report of the subgroups based on your selection on the CuSum Chart Report Options dialog box (see Figure 5-71). The report shows the values that are plotted on the control chart, including values for CuSum and the range. It notes points that are beyond the control limits with an asterisk, and points that are excluded with an X. You can create a report that displays all the subgroups; subgroups beyond the control limits, CuSums beyond the limits, ranges beyond the limits, or subgroups that were excluded.



Subgroup	C+	Mean N+	Cusum C-	N-	Range
1	0.0	0	0.163439	1	0.6
2	0.0	0	0.286879	2	0.9
3	0.0394393	1	0.130318	3	0.8
4	0.0	0	0.133757	4	0.9
5	0.0494393	1	0.0	0	1.3
6	0.248879	2	0.0	0	1.1
7	0.368318	3	0.0	0	1.3
8	0.447757	4	0.0	0	1.3
9	0.517197	5	0.0	0	1.3
10	0.0166358	6	0.383439	1	1.9

Figure 5-71. CuSum Chart Report

Use the *CuSum Chart Report Options* dialog box to choose the report you want to create, and to enter the number of decimal places that will be used for displaying the limits (see Figure 5-72).

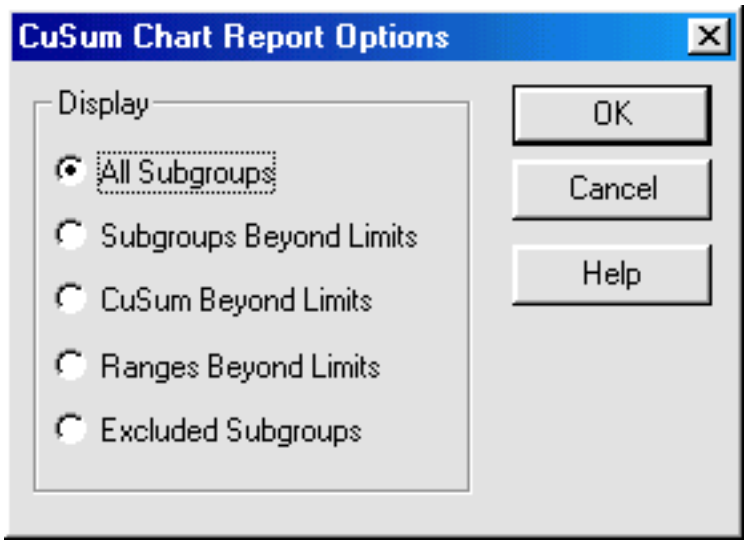


Figure 5-72. CuSum Chart Report Options Dialog Box

Graphical Options

Cumulative Sum Chart

The Cumulative Sum Chart option creates a plot of the cumulative sum designed to monitor deviations from target for each of the subgroups (see Figure 5-73). The chart detects shifts in the process mean and notes points that are beyond the control limits.

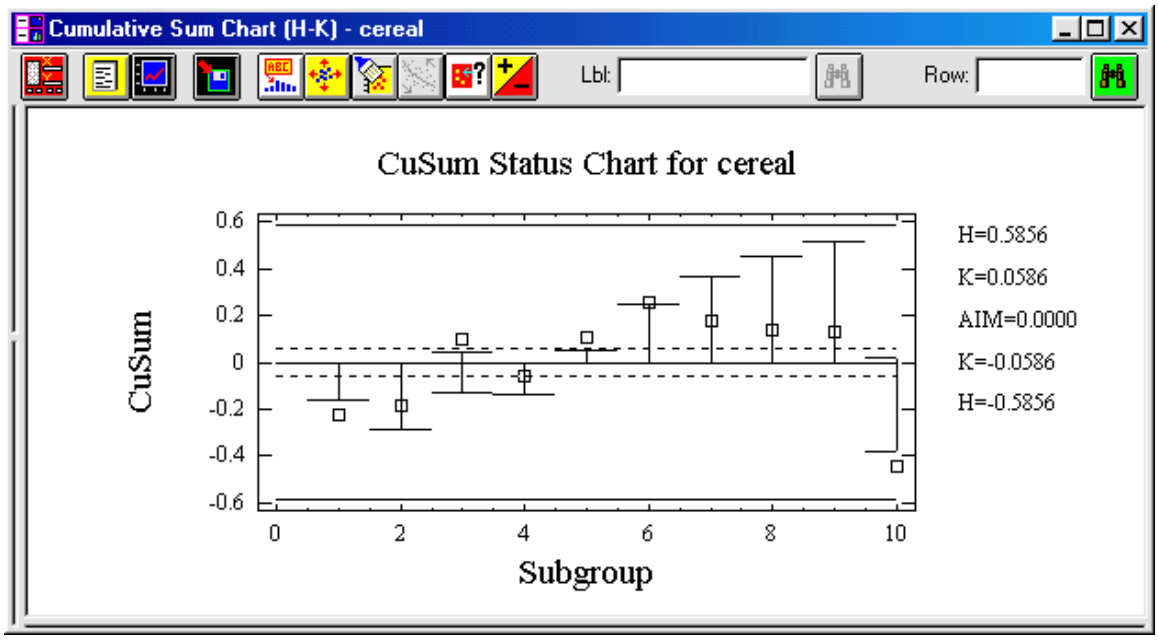


Figure 5-73. Cumulative Sum Chart

Use the *CuSum Chart Options* dialog box to enter the number of decimal points that will display for the control limits (see Figure 5-74).

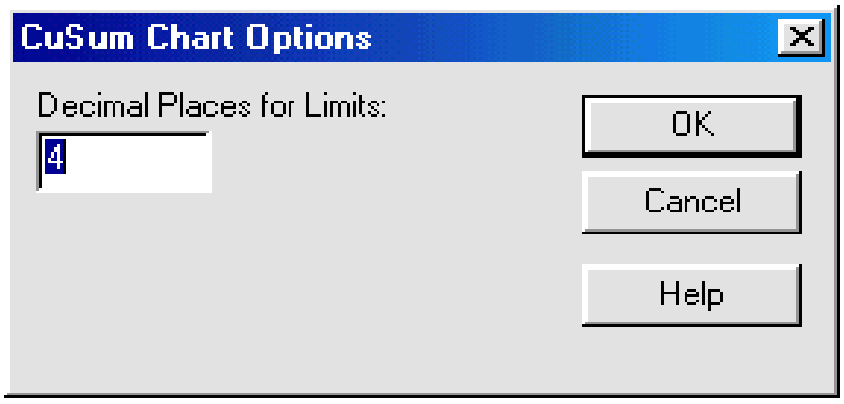


Figure 5-74. Cu Sum Chart Options Dialog Box

Range Chart

The Range Chart option creates a plot of the ranges for each of the subgroups (see Figure 5-75). It notes the points that are beyond the control limits.

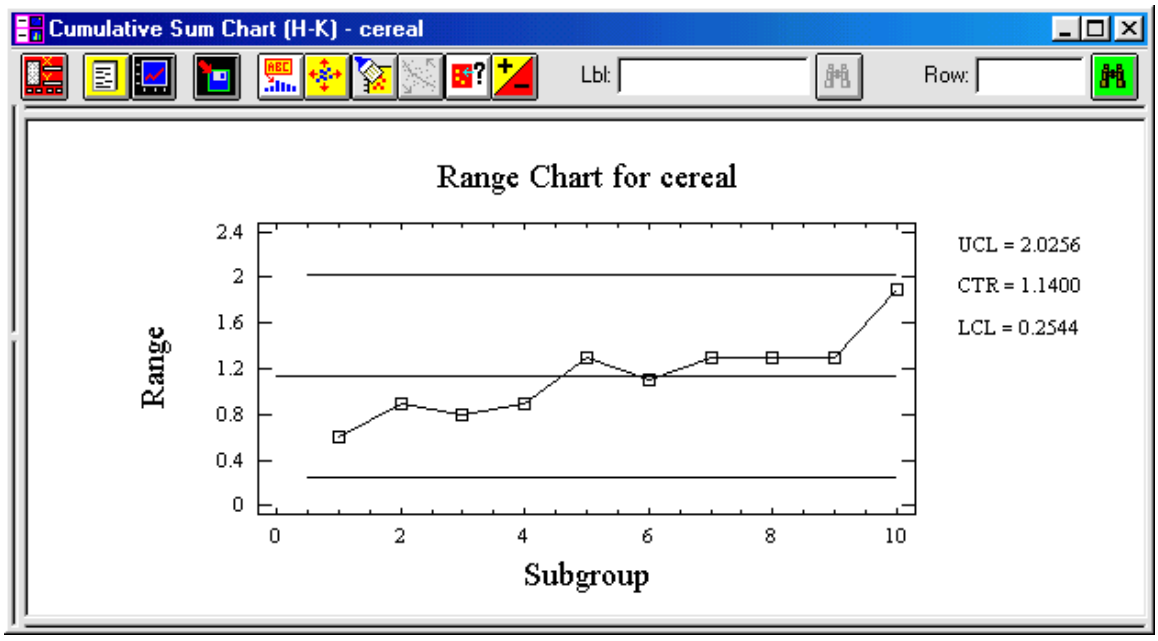


Figure 5-75. Range Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; to indicate if you want the simple moving average of the subgroup statistics superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the subgroup statistics superimposed on the chart, and if so, to enter a value for lambda; and to enter the number of decimal places that will be used for displaying the limits. *See Figure 5-11 for an example of this dialog box.*

ARL Curve

The ARL (Average Run Length) Curve option creates a plot that shows the ARL for the CuSum Chart (H-K) as a function of the process mean (see Figure 5-76). For example, if the process is actually running at the centerline, the chart will not create an out-of-control signal on average for several samples. If the process moves away from the centerline, the ARL will change accordingly. The plot is helpful when you need to select an adequate sampling plan to monitor the process.

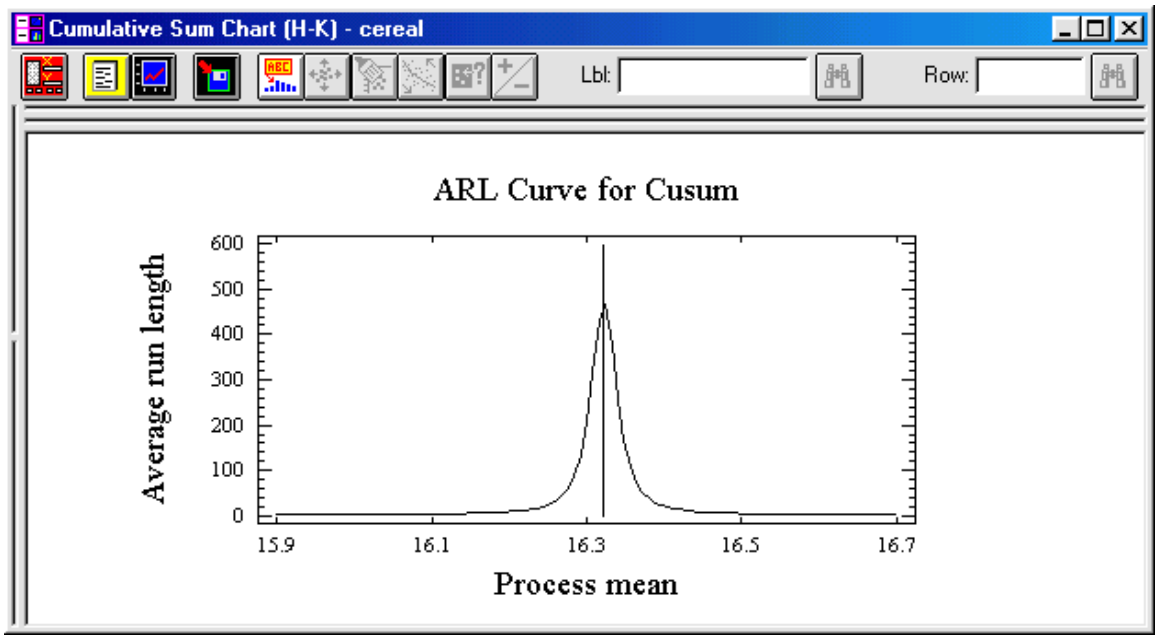


Figure 5-76. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are six selections: Cumulative Sum, Ranges, Sizes, Labels, Process Mean, and Process Sigma.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the CuSum Individuals Chart (H-K) Analysis

The CuSum Chart (H-K) Analysis is also called the *algorithmic* or *tabular* CuSum. The technique accumulates deviations above the target separately from deviations below the target. Those accumulated deviations above the target become the one-sided upper CuSums. The accumulated deviations below the target become the one-sided lower CuSums. The process is determined to be out of control when either type of CuSum exceeds the decision interval, called H.

The CuSum Individuals Chart (H-K) Analysis produces a time-weighted chart of the individual observations. This analysis plots the cumulative sums of the deviations of the sample from the target value. Use this analysis when the subgroup size is 1.

You can use the analysis to maintain current control of a process. An upward or downward trend in the data indicates that the process mean has shifted and the process is out of control. The CuSum Individuals Chart allows you to detect sudden and persistent change in the process average more rapidly than variables controls charts. By detecting the changes sooner, you can adjust the process before large variations occur. This analysis is particularly useful in chemical and process industries where individual items may be difficult to form into subgroups.

To Access the CuSum Individuals Chart (H-K) Analysis

1. Choose SPECIAL... QUALITY CONTROL... TIME-WEIGHTED CHARTS... CUSUM INDIVIDUALS CHART (H-K)... from the Menu bar to display the Analysis dialog box shown in Figure 5-77.

2. Complete the dialog box and click OK to display the Analysis Summary and the Mean Chart in the Analysis window.

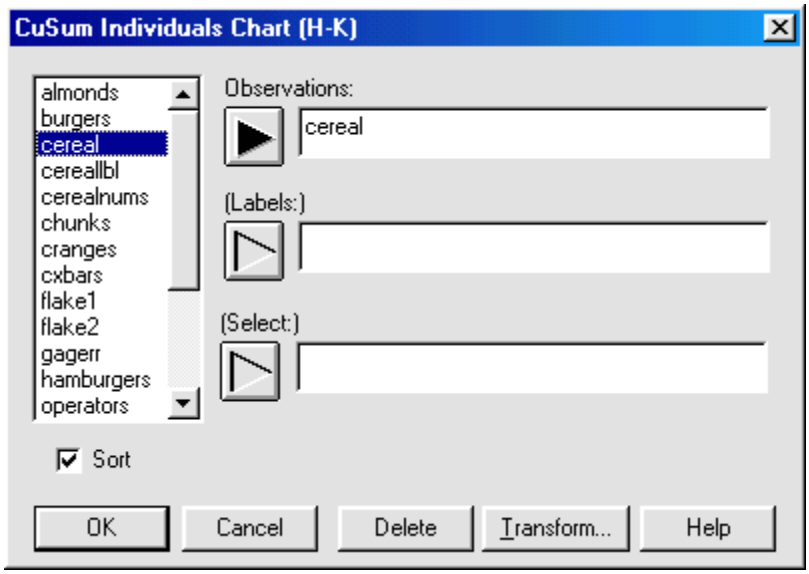


Figure 5-77. CuSum Individuals (H-K) Chart Analysis Dialog Box

Tabular Options

Analysis Summary
The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 5-78). The program constructs the control charts under the assumption that the data come from a normal distribution with values for the mean and standard deviation, which are estimated from the data.

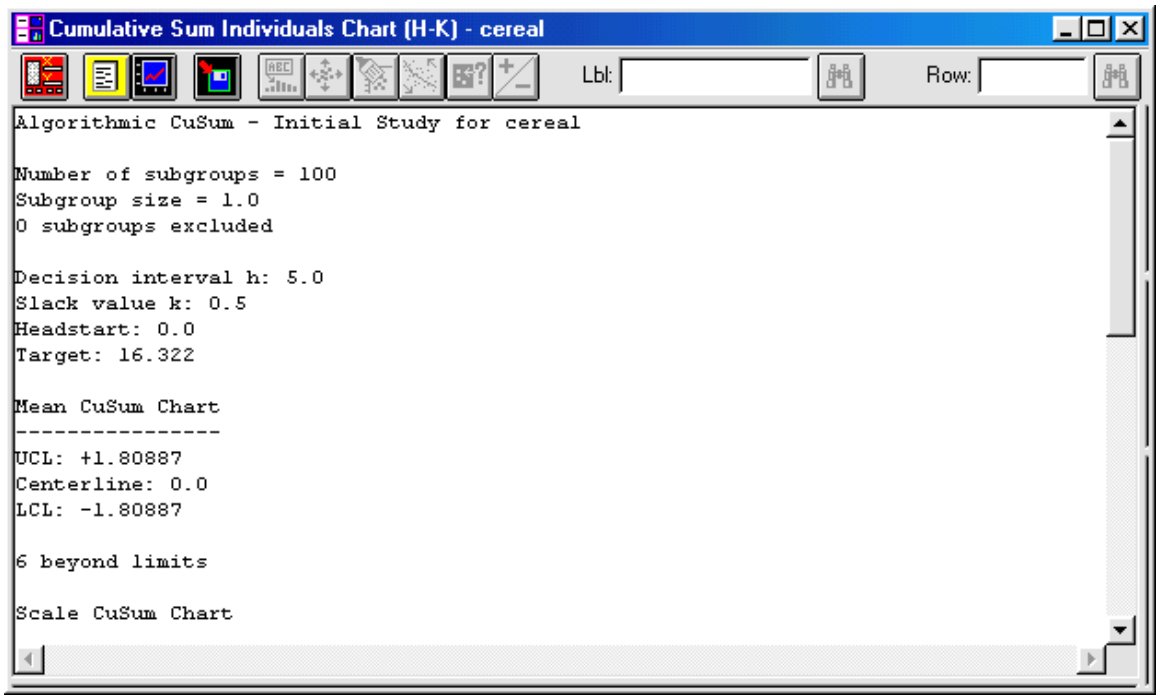


Figure 5-78. Analysis Summary

For the Mean CuSum Chart and the Scale CuSum Chart, the report displays the values for the upper and lower control limits, the centerline, and the number of observations beyond the limits. The report also shows the number of observations and the number of observations excluded from the study. It provides estimates for the process mean and process sigma. For a control-to-standard study, the report includes standard statistics.

Use the *CuSum (H-K) Chart Options* dialog box to indicate if the study will be an initial or a control to standard; to enter a value for sigma for the decision interval (H); to enter a value for sigma for the reference value (K); to enter a number that will be used to calculate the average run length (ARL); to enter a number that will shift the initial values of the upper and lower CuSums; to indicate if the CuSum control limits will be two-sided, upper only, or lower only; and if the data should be normalized; and to enter values for sigma for the upper and lower Scale control

limits (see Figure 5-79). For a control-to-standard study, you can specify the values that will be used for the mean and sigma parameters.

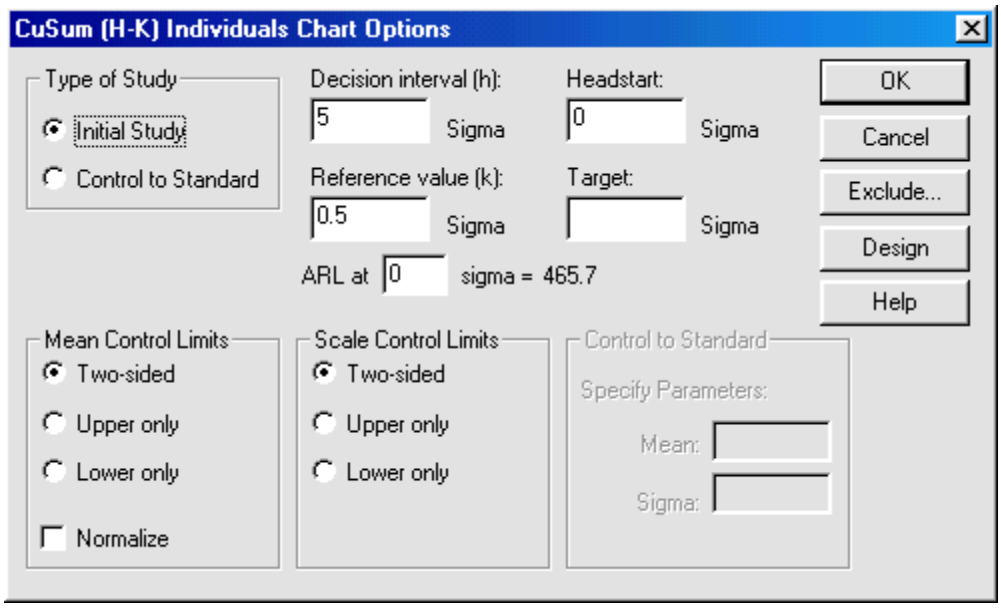


Figure 5-79. CuSum (H-K) Individuals Chart Options Dialog Box

Clicking the Design... button displays the Design CuSum Chart dialog box you use to enter a value for the in-control ARL and for the size of the sigma shift (see Figure 5-80).

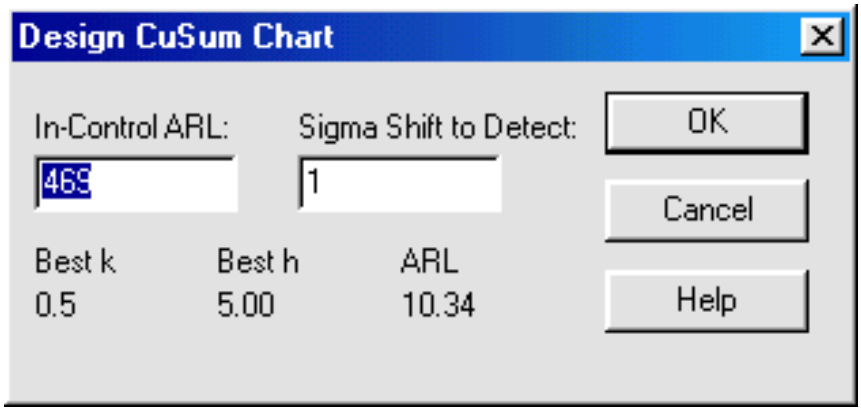
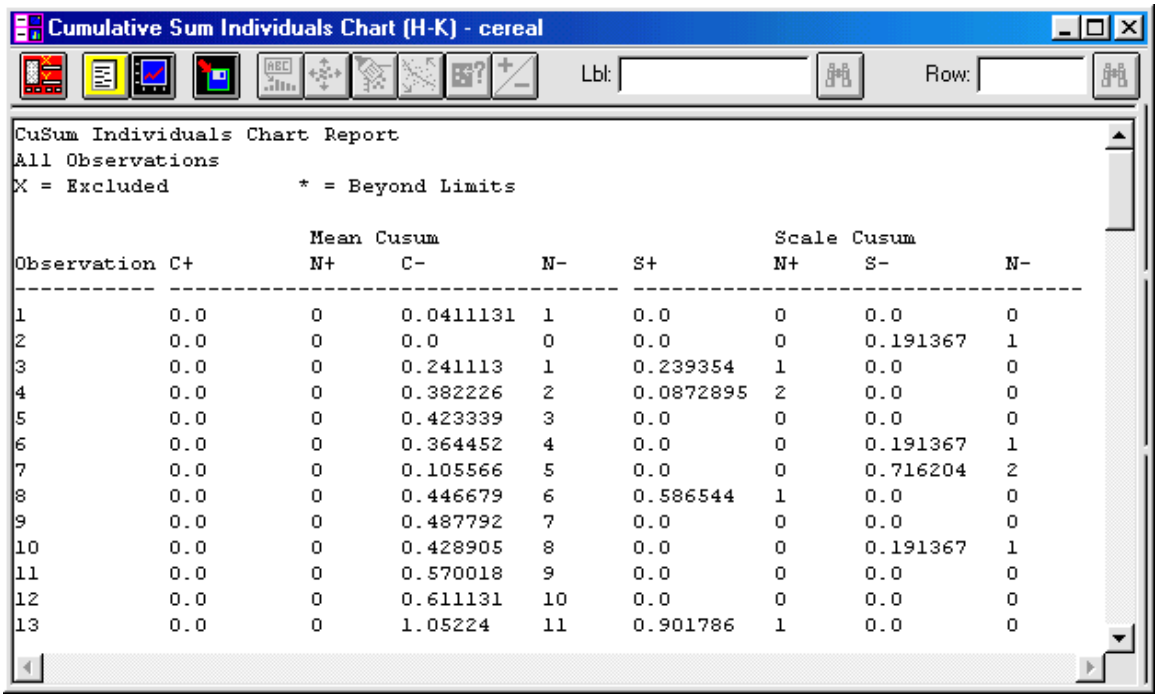


Figure 5-80. Design CuSum Chart Dialog Box

CuSum Individuals Chart Report

The CuSum Individuals Chart Report option creates a report of the observations based on your selection on the CuSum Individuals Chart Report Options dialog box (see Figure 5-81). The report shows the values that are plotted on the control chart, including values for the Mean CuSum and Scale CuSum. It notes points that are

beyond the control limits with an asterisk, and points that are excluded with an X. You can create a report that displays all the observations; observations beyond the control limits, CuSum values beyond the limits, Scale CuSum values beyond the limits, or observations that were excluded.



Observation	Mean Cusum C+	N+	C-	N-	Scale Cusum S+	N+	S-	N-
1	0.0	0	0.0411131	1	0.0	0	0.0	0
2	0.0	0	0.0	0	0.0	0	0.191367	1
3	0.0	0	0.241113	1	0.239354	1	0.0	0
4	0.0	0	0.382226	2	0.0872895	2	0.0	0
5	0.0	0	0.423339	3	0.0	0	0.0	0
6	0.0	0	0.364452	4	0.0	0	0.191367	1
7	0.0	0	0.105566	5	0.0	0	0.716204	2
8	0.0	0	0.446679	6	0.586544	1	0.0	0
9	0.0	0	0.487792	7	0.0	0	0.0	0
10	0.0	0	0.428905	8	0.0	0	0.191367	1
11	0.0	0	0.570018	9	0.0	0	0.0	0
12	0.0	0	0.611131	10	0.0	0	0.0	0
13	0.0	0	1.05224	11	0.901786	1	0.0	0

Figure 5-81. CuSum Individuals Chart Report

Use the *CuSum Individuals Chart Report Options* dialog box to choose the report you want to create, and to enter the number of decimal places that will be used for displaying the limits (see Figure 5-82)

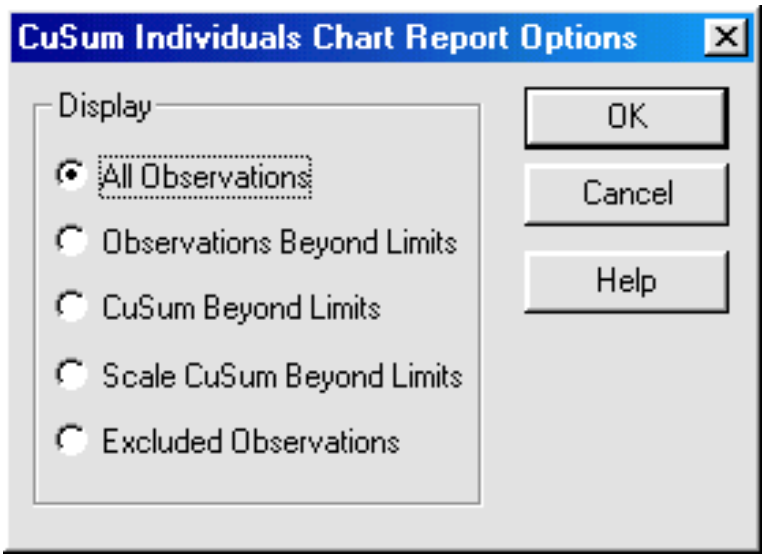


Figure 5-82. CuSum Individuals Chart Report Options Dialog Box

Graphical Options

CuSum Chart

The CuSum Chart option creates a plot of the cumulative sum that monitors deviations from target for each of the measurements (see Figure 5-83). Upper and lower control limits are displayed and determine if the process in statistical control. If the process is in control, all of the points should be within the control limits.

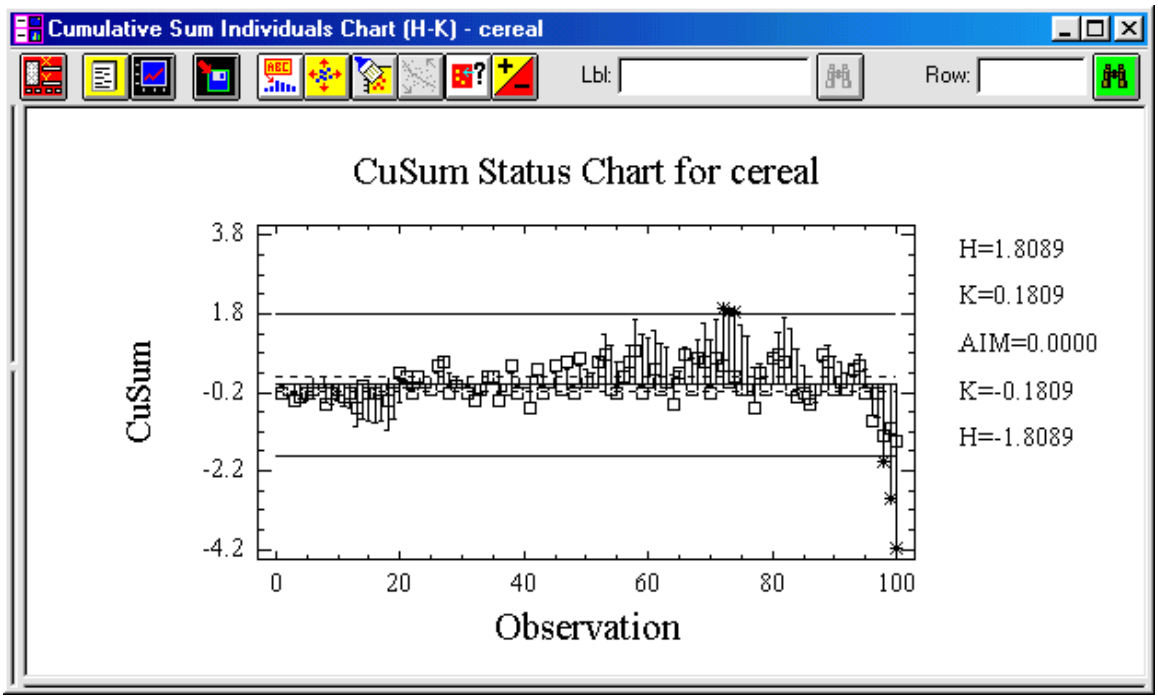


Figure 5-83. CuSum Chart

Use the *CuSum Chart Options* dialog box to enter the number of decimal places that should be used for displaying the control limits (see Figure 5-84).

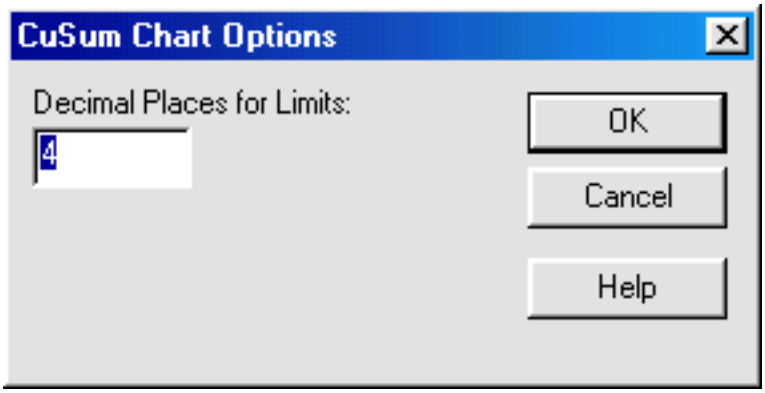


Figure 5-84. CuSum Chart Options Dialog Box

Scale CuSum Chart

The Scale CuSum Chart option creates a cumulative sum plot for the scaled values of the measurements (see Figure 5-85). The plot is designed to detect changes in the standard deviation of the process; it notes points that are beyond the control limits.

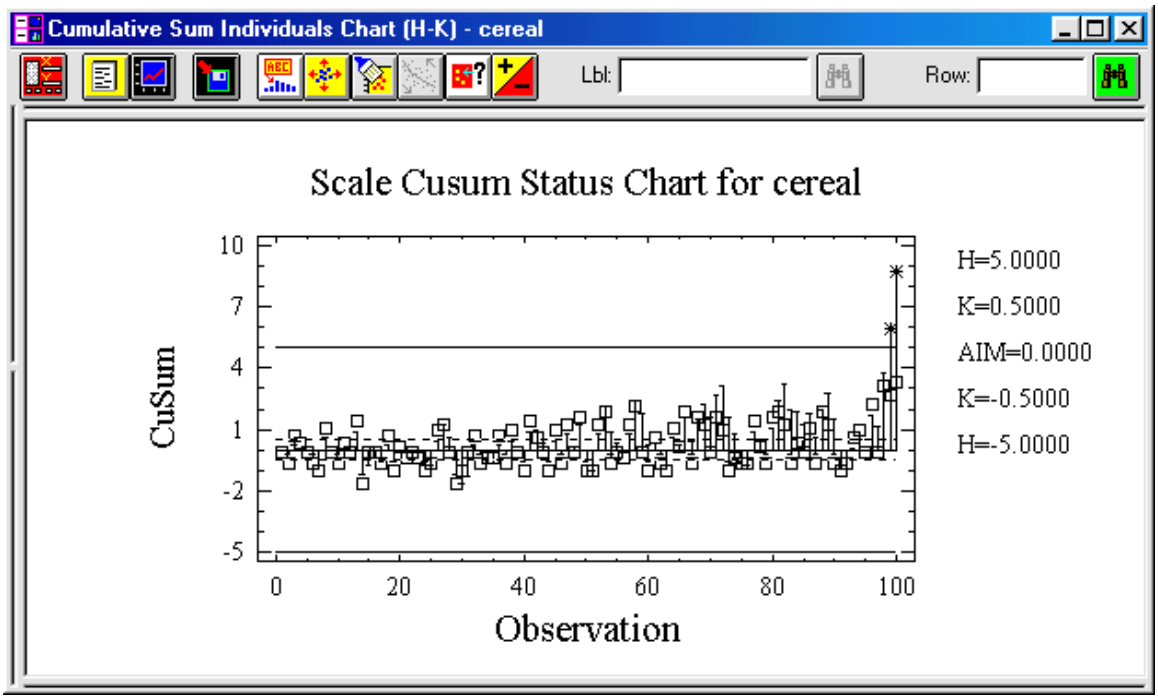


Figure 5-85. Scale CuSum Chart

Use the *CuSum Chart Options* dialog box to enter the number of decimal places that should be used for displaying the control limits. *See Figure 5-84 for an example of this dialog box.*

ARL Curve

The ARL (Average Run Length) Curve option creates a plot that shows the ARL for the CuSum Chart as a function of the process mean (see Figure 5-86). For example, if the process is actually running at the centerline, the chart will not create an out-of-control signal on average for several samples. If the process moves away from the centerline, the ARL will change accordingly. The plot is helpful when you need to select an adequate sampling plan to monitor the process.

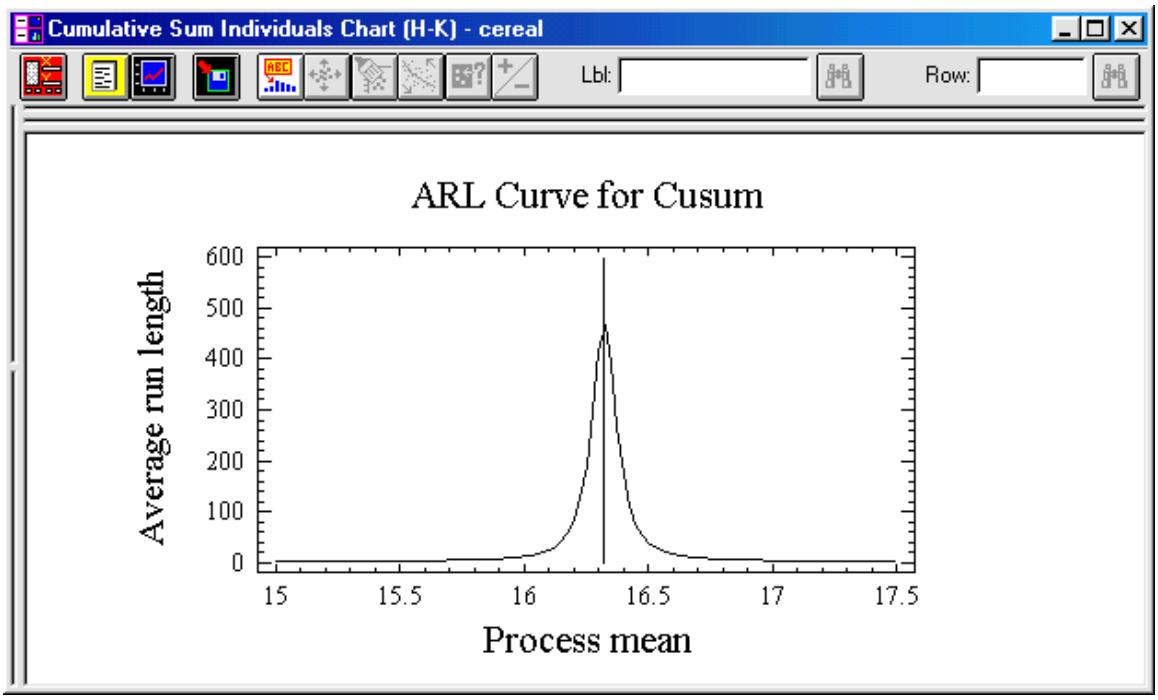


Figure 5-86. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are six selections: Cumulative Sum, Moving Ranges, Labels, Process Mean, Process Sigma, and Included Observations.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

References

AT&T. 1956. *Statistical Quality Control Handbook, Select Code 700-444.* Indianapolis: AT&T Technologies.

Duncan, A J. 1974. *Quality Control and Industrial Statistics*, fourth edition. Homewood, Illinois: Richard D. Irwin, Inc.

Montgomery, D. C. 1997. *Introduction to Statistical Quality Control*, third edition. New York: John Wiley & Sons, Inc.

Chapter 6

USING MULTIVARIATE CONTROL CHARTS

Process-monitoring problems that involve several related variables are sometimes called *multivariate quality control* or *process monitoring problems*. The original work in multivariate quality control was done by Hotelling (1947), who applied his procedures to bombsight data during World War II. The subject is important today, because automatic inspection procedures make it relatively easy to measure many parameters on each unit of product manufactured.

Typically, process monitoring applies to processes in which only one variable is measured and tested. One disadvantage is that for a single process, many variables can be monitored and even controlled. Multivariate quality control methods overcome this disadvantage by monitoring several variables simultaneously. Engineers and manufacturers who use multivariate quality control methods can more effectively monitor the stability of their process.

Multivariate quality control is more complex than univariate SPC, but it is a more realistic representation because in the real world, processes usually have more than one variable that is measured independently. One way to see the advantages of multivariate quality control is to superimpose univariate control charts on top of each other, to create a graph of all the points on each control chart in the same area of space. However, if the variables are correlated, as they often are when they are from the same process, superimposing univariate charts is not a very accurate method for monioring processes.

In multivariate situations, the probability that a process is completely in control is less than in the univariate case. Similarly, the likelihood of a multivariate process being completely out of control is less than that in univariate situations. Using multivariate control charts, it is possible to maintain a specific error rate, while taking advantage of cross correlation between the variables, and the process can be analyzed for stability without the complication of maintaining many control charts at once (Montgomery, 1997).

The Multivariate Control Chart Analysis in STATGRAPHICS *Plus* lets you construct a single control chart for two or more variables. The intent of the analysis is to determine if all of the cases come from a single multivariate normal distribution.

To Access the Multivariate Control Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... MULTIVARIATE CONTROL CHARTS... from the Menu bar to display the Multivariate Control Chart Analysis dialog box shown in Figure 6-1.

2. Complete the dialog box and click OK to display the Analysis Summary and the Multivariate Control Chart in the Analysis window.

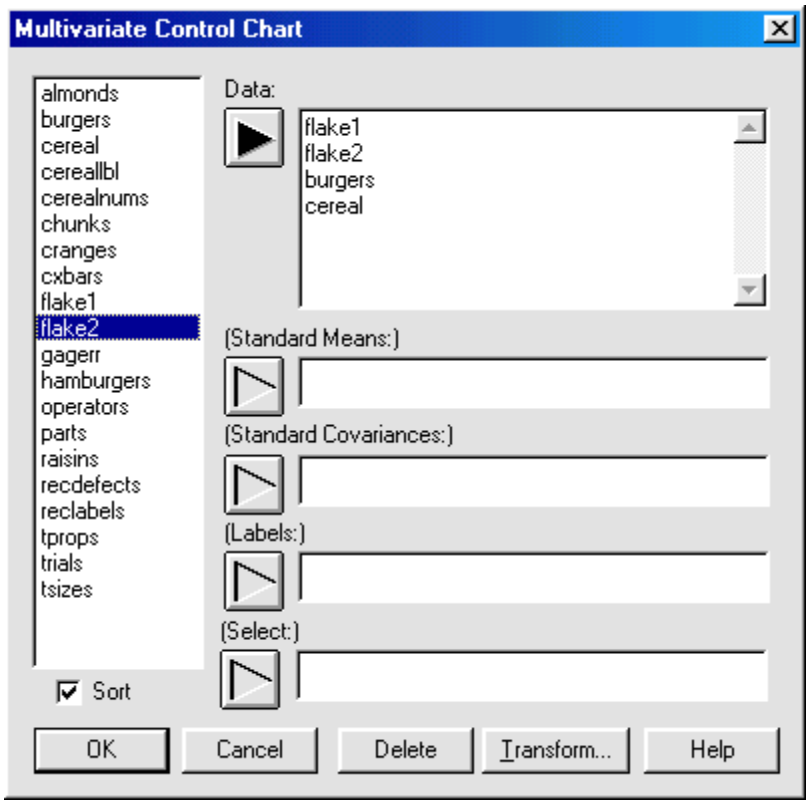


Figure 6-1. Multivariate Control Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis that shows the names of the variables, the number of complete cases, and the number of cases excluded from the analysis (see Figure 6-2). It also shows the values for the upper control limit and alpha, and the number of cases beyond the limits. The charts the analysis produces are constructed using the assumption that the data come from a multivariate normal distribution.

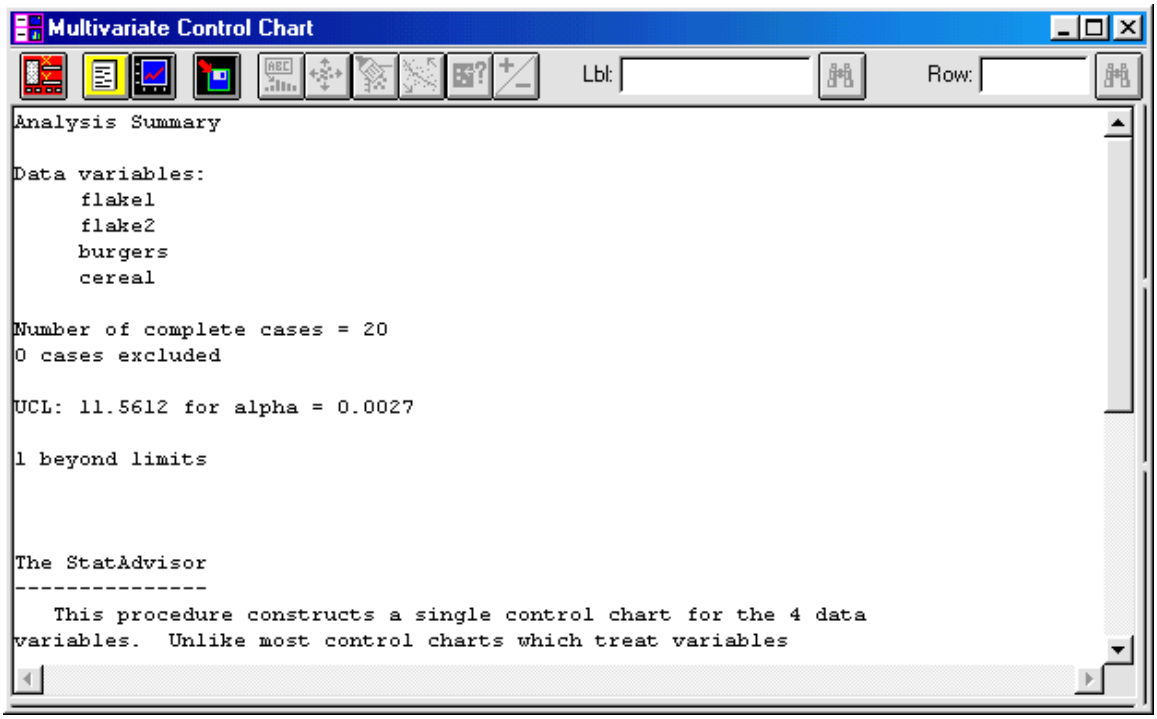


Figure 6-2. Analysis Summary

Use the *Multivariate Chart Options* dialog box to enter a value for the alpha risk (see Figure 6-3). The alpha risk, which is the probability of a Type I error, determines the probability of declaring a process out of control when, in fact, it is not. Enter a number greater than 0 and less than 100. If you are performing a Control-to-Standard study, you can also enter a value for the standard sample size.

Note: Changes you make to this text box also changes the UCL on the Multivariate Control Chart.

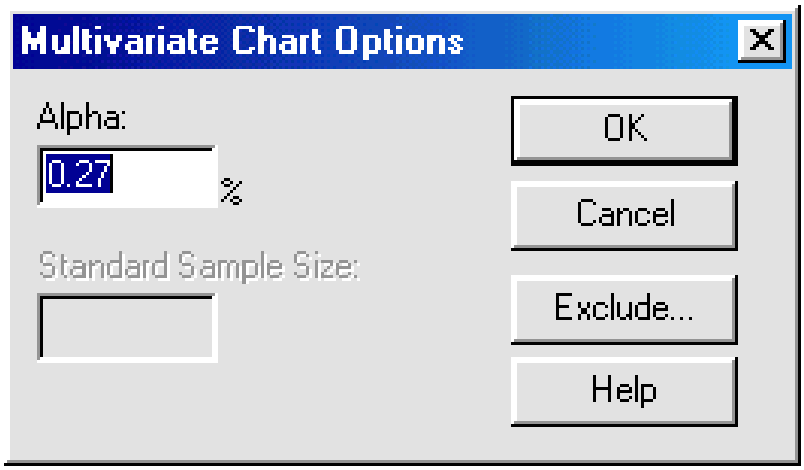


Figure 6-3. Multivariate Chart Options Dialog Box

Multivariate Chart Report

The Multivariate Chart Report option creates and a table that lists the T-Squared value for each of the cases (see Figure 6-4). The T-Squared value is a measure of how far each case is from the centroid of the data.

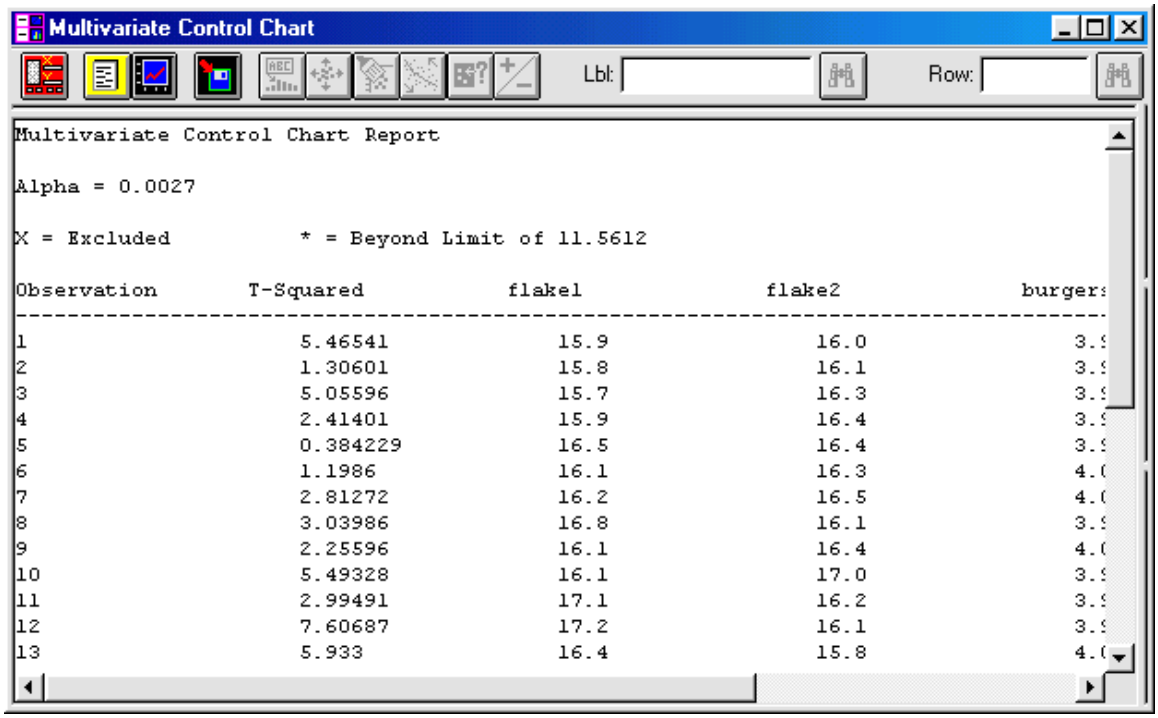


Figure 6-4. Multivariate Chart Report

Use the *Chart Report Options* dialog box to indicate if individual data values should display in the report, which is the default (see Figure 6-5). If you deselect the default, the table displays only the observation number and the corresponding T-squared columns of data.

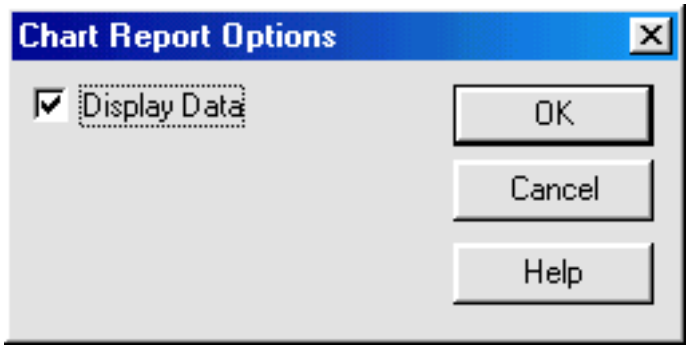


Figure 6-5. Chart Report Options Dialog Box

Graphical Options

Multivariate Control Chart

The Multivariate Control Chart option displays a plot that shows one point for each multivariate observation (see Figure 6-6). The closer the Hotelling T-Squared statistic is to 0, the closer the observation is to the multivariate mean of the data; the value plotted on the vertical axis is Hotelling s T-Squared. If you provide standard means, the observation is closer to the corresponding standard mean. Observations beyond the control limits are shown with an asterisk.

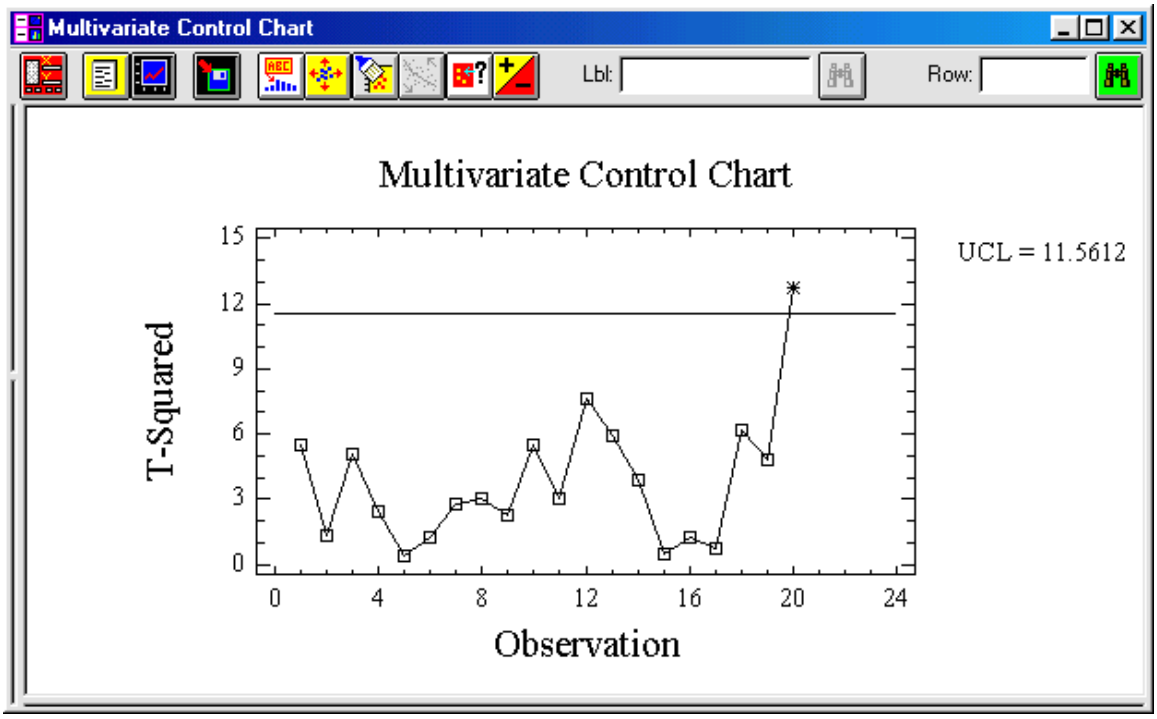


Figure 6-6. Multivariate Control Chart

Use the *Multivariate Control Chart Options* dialog box to indicate if points or glyphs will appear on the plot; and to enter the number decimal places that will be used for displaying the limits (see Figure 6-7).

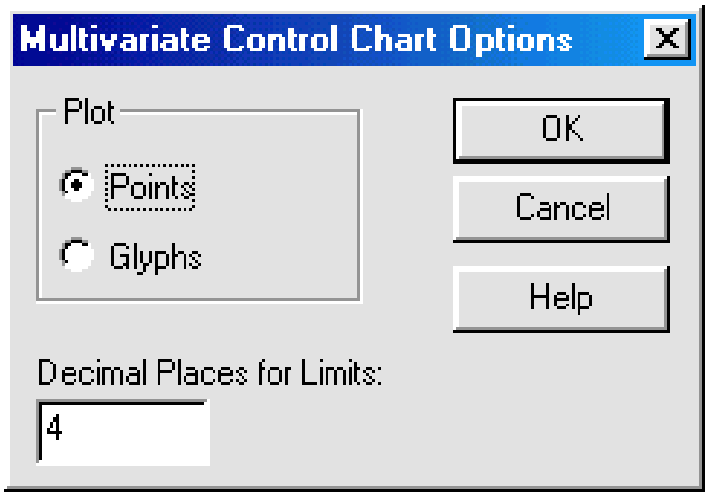


Figure 6-7. Multivariate Control Chart Options Dialog Box

Key Glyph

The Key Glyph option displays a key glyph that shows the definition of the optional glyphs that can be plotted on the Multivariate Control Chart (see Figure 6-8). The length of each ray is proportional to the value of a single variable. The scale for the ray is based on the minimum and maximum values in the dataset. If several points are beyond the control limit, the glyphs may be helpful in identifying patterns among the variables.

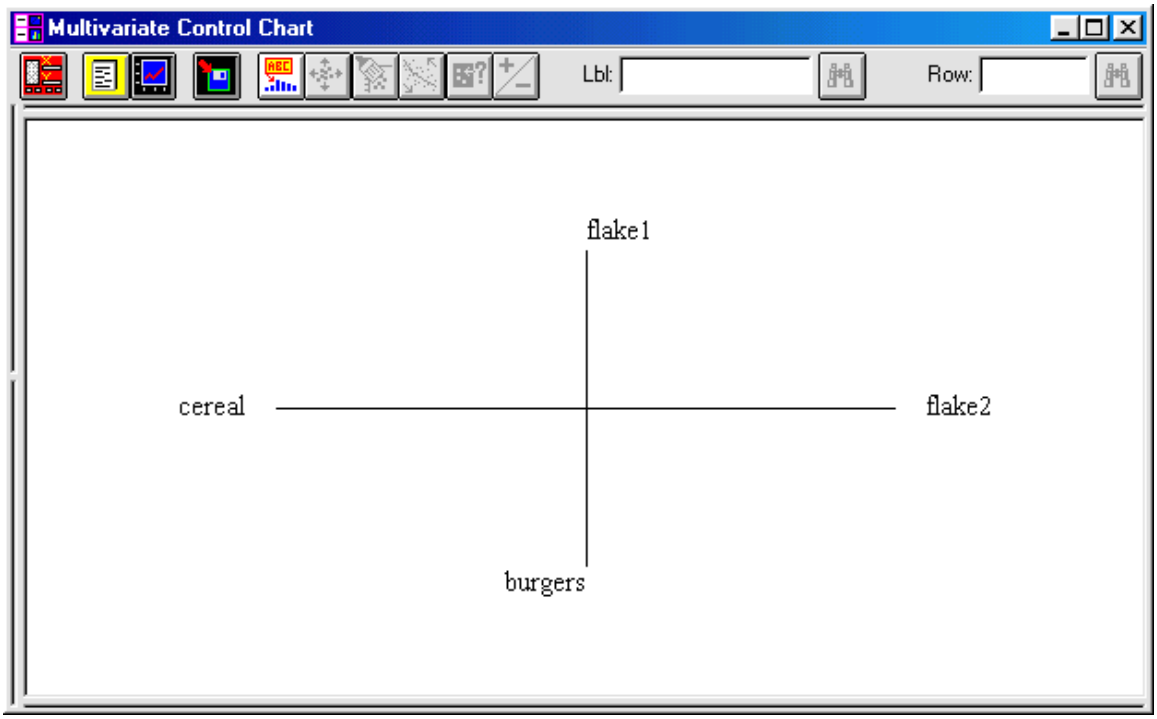


Figure 6-8. Key Glyph

Control Ellipse

The Control Ellipse option displays a plot that shows the points outside the control ellipse, which corresponds to points outside the control limit (see Figure 6-9). This plot is available only when you analyze two variables.

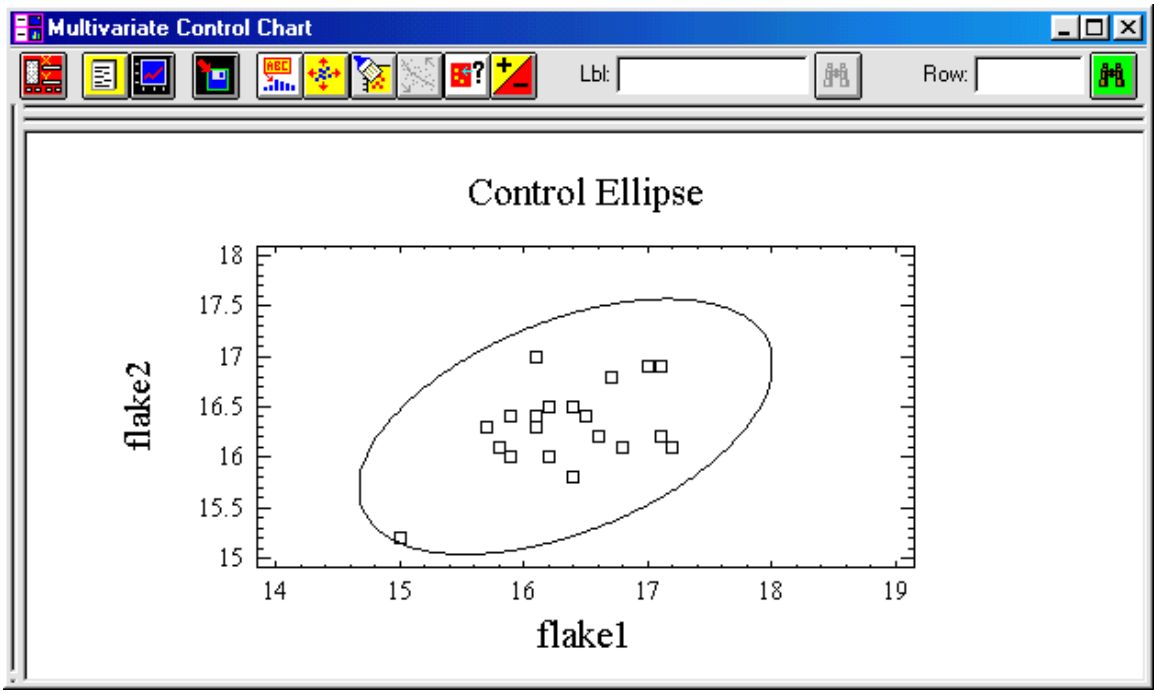


Figure 6-9. Control Ellipse

Saving the Results

The Save Results Options dialog box allows you to select the results you want to save. There are four selections: T-Squared, Means, Covariances, and Labels.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

References

Hotelling, H. 1947. Multivariate Quanity Control. *Techniques of Statistical Analysis*. Edited by Eisenhart, Hastay, and Wallis. New York: McGraw-Hill.

Montgomery, D. C. 1997. *Introduction to Statistical Quality Control*, third edition. New York: John Wiley & Sons, Inc.

Chapter 7

Using Special Purpose SPC Control Charts

This chapter focuses on other special purpose SPC control charts you can use:

- **ARIMA Chart Analysis**
  This analysis combines autoregressive analysis procedures with those of moving averages to construct a trend line for subgroup data that accounts for both systematic error (autocorrelation) and nonsystematic (random) error.

- **ARIMA Individuals Chart Analysis**
  This analysis is the same as the ARIMA Chart Analysis except that you use individual observations rather than subgroups.

- **Toolwear Chart Analysis**
  This analysis is a useful process-control technique that can be applied to the tool-wear problem. This analysis uses subgroup data to create a trend line that is used to determine when a process should be reset or a tool replaced.

- **Toolwear Individuals Chart Analysis**
  This analysis is the same as the Toolwear Chart Analysis except that you use individual observations rather than subgroups.

- **Acceptance Chart Analysis**
  This analysis uses an X-bar chart to monitor the fraction of nonconforming units or the fraction of units that exceed specifications. It uses subgroup data.

- **Acceptance Individuals Chart Analysis**
  This analysis is the same as the Acceptance Chart Analysis except that you use individual observations rather than subgroups.

Using the ARIMA Analysis

Autoregressive Integrated Moving Average (ARIMA) models are a complex set of statistical techniques for time-series analysis that combines autoregressive analysis procedures with those of moving averages. A researcher using ARIMA models is able to construct a trend line that accounts for both systematic error (autocorrelation) and nonsystematic (random) error.

Over the years, ARIMA models have been studied extensively. Yule first introduced Autoregressive (AR) models in 1926, Walker generalized them in 1931, and Slutzky used moving average (MA) models in 1937. Wold, however, provided the theoretical foundations of the combined ARMA processes in 1938. Building on Wold's work, ARMA models developed in three directions:

- identification and estimation procedures (for AR, MA, and mixed ARMA processes)

- seasonal time series

- nonstationary processes (ARIMA) (Makridakis, Wheelwright, and McGee, 1983).

Box and Jenkins (1976) put together the much-needed information that was necessary to understand and use univariate time-series ARIMA models. Their approach consisted of three phases: identification, estimation and testing, and application.

Many researchers, including Montgomery (1997), point out the problem of conventional control charts not working well when ″. . . quality characteristics contain even low levels of correlation over time″ . . . ″because these control charts will give misleading results in the form of too many false alarms if the data are correlated.″

Montgomery further says that an approach useful in dealing with autocorrelated data is to ″directly model the correlative structure with an appropriate time-series model, use that model to remove the autocorrelation from the data, and apply control charts to the residuals.″

The ARIMA and ARIMA Individuals charts analyses in STATGRAPHICS *Plus*, use Montgomery′s approach. The analyses are designed to handle serially correlated subgroup or individuals data. They also provide complete ARIMA modeling without limits on the order of autoregressive or moving-average processes.

To Access the ARIMA Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... SPECIAL PURPOSE CONTROL CHARTS... ARIMA CHART... to display the Analysis dialog box (see Figure 7-1).

2. Complete the dialog box and click OK to display the Analysis Summary and the ARIMA Chart in the Analysis window.

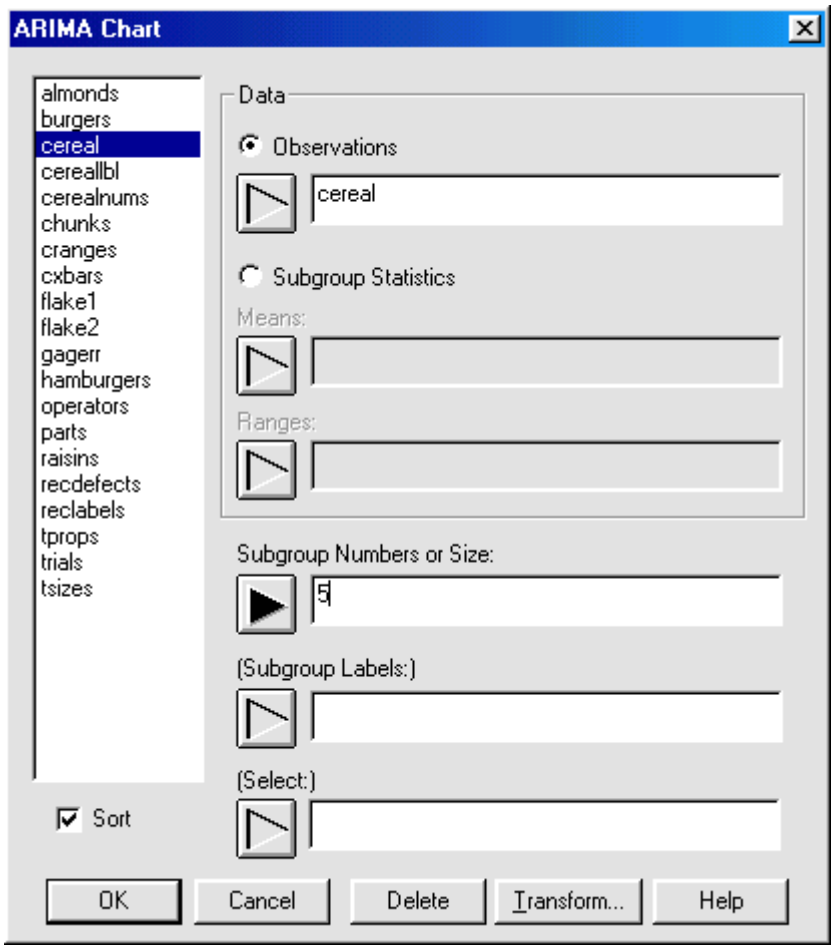


Figure 7-1. ARIMA Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 7-2). The summary shows the location of the limits on standard ARIMA and Range charts. The charts are constructed using the assumption that the data come from a normal distribution with values for the mean and standard deviation estimated from the data.

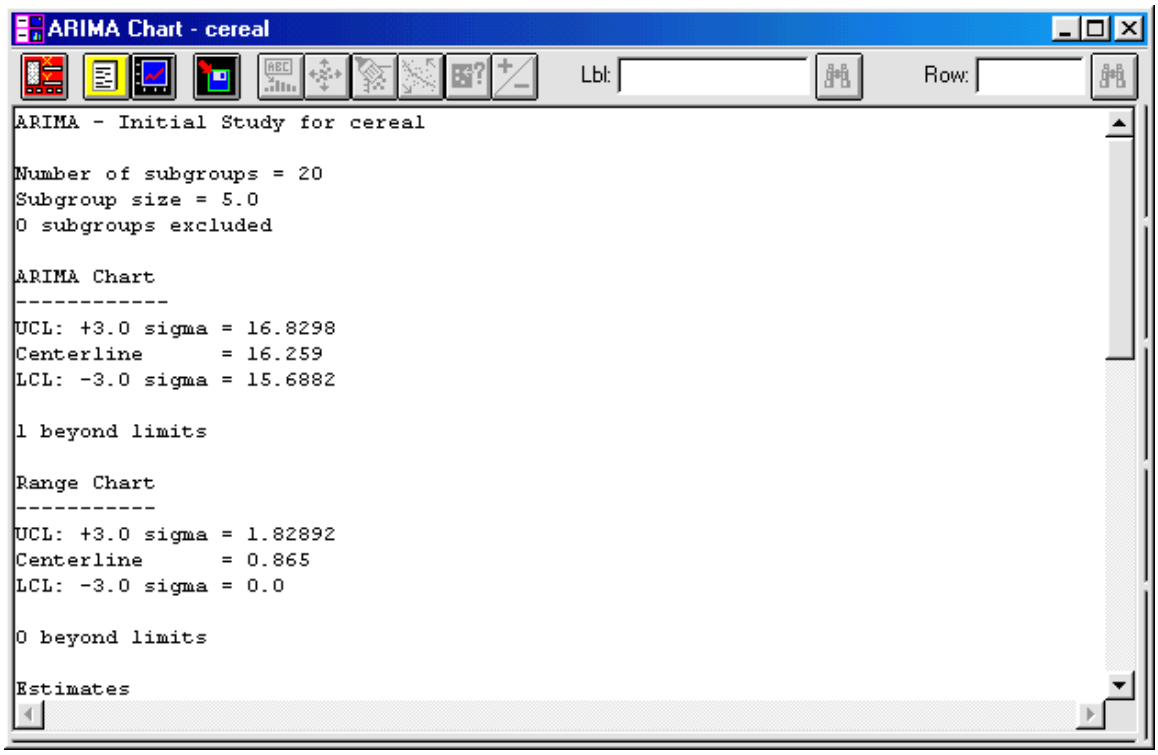


Figure 7-2. Analysis Summary

For both the ARIMA Chart and the Range Chart, the report displays the values for the upper and lower control limits, the centerline, and the number of subgroups beyond the limits. It also shows the number of subgroups, the subgroup size, and the number of subgroups excluded from the study. It provides estimates for the process mean, process sigma, and the mean range.

The ARIMA Model Summary table displays the parameters used in the ARIMA model and the values of the estimated coefficients and their associated standard error, *t*-statistic, and *p*-values. The *t*-statistics and the *p*-values indicate if the coefficients are significant. For example, when testing at a 95 percent level of confidence, a coefficient with a *p*-value less than .05 is statistically significant. The table also shows if Backforecasting was used in the calculation, and provides values for the estimated white noise variance and standard deviation.

Use the *ARIMA Chart Options* dialog box to indicate if the study will be an initial or a control to standard; and to enter values for the upper and lower sigma for the ARIMA Control Limits and Range Control Limits (see Figure 7-3).

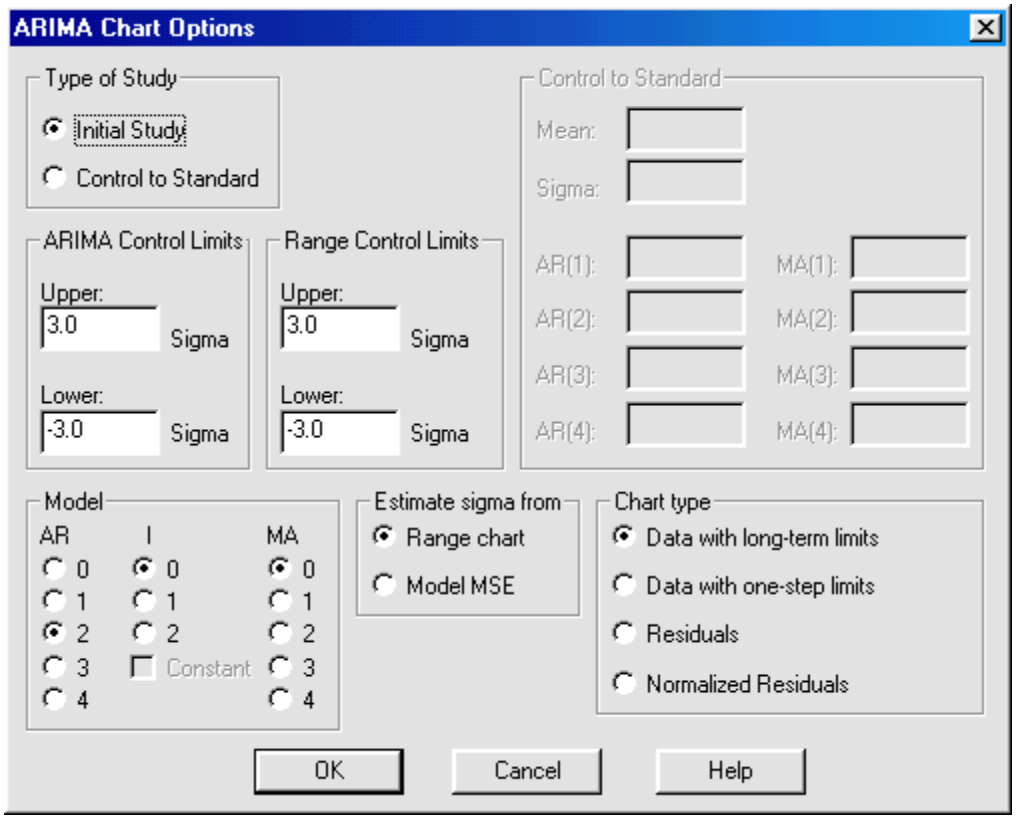


Figure 7-3. ARIMA Chart Options Dialog Box

For both types of studies, you can also choose the order of the ARIMA model, allowing for up to fourth-order AR and MA terms and up to second-order differencing. You use the Model options and choose from each of the three columns, the parameters you want estimated; that is, from the AR column, the number of nonseasonal autoregressive parameters; from the I column, the number of integrated parameters; and from the MA column, the number of nonseasonal moving-average parameters.

You can also indicate if you want sigma estimated from the Range Chart or the Model MSE; and choose the type of ARIMA chart you want to create: Data with long-term limits, Data with one-step limits, Residuals, or Normalized residuals.

For a Control-to-Standard Study, you can enter values for the Mean and Sigma, and for each of the AR and MA model terms you choose from the Model options portion of the dialog box. *See Online Help for a complete description of each of these text boxes.*

ARIMA Chart Report

The ARIMA Chart Report option creates a report of the subgroups based on your selection on the ARIMA Chart Report Options dialog box (see Figure 7-4). The report shows the values that are plotted on the control chart, including values for the subgroup size, X-bar, and range. It notes points that are beyond the control limits with an asterisk.

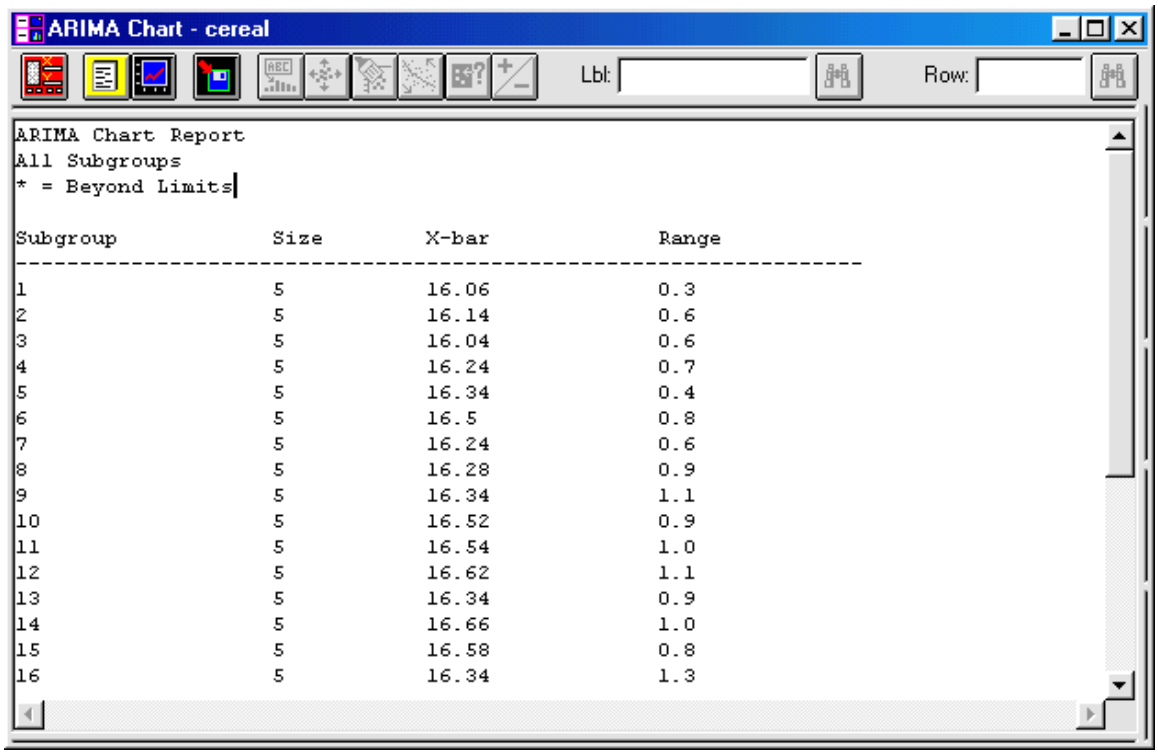


Figure 7-4. ARIMA Chart Report

Use the *ARIMA Chart Report Options* dialog box to choose the report you want to create (see Figure 7-5). You can create a report that displays all the subgroups; subgroups beyond the control limits, X-bars beyond the limits, or ranges beyond the limits.

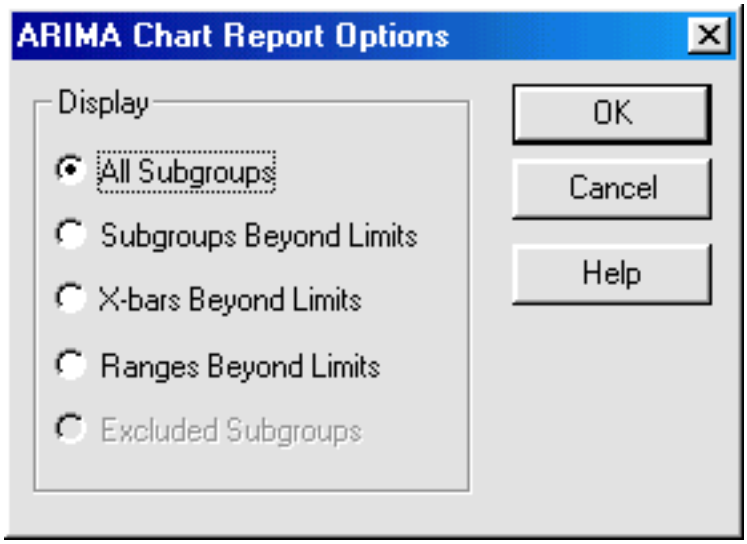


Figure 7-5. ARIMA Chart Report Options Dialog Box

Runs Tests (Available for Residuals or Normalized Residuals Charts)

The Runs Tests option performs a battery of tests that help determine if a sequence of observations is in a nonrandom pattern, which indicates that a process is out of control (see Figure 7-6). To use this option, choose either Residuals or Normalized Residuals from the Chart Type portion of the ARIMA Chart Options dialog box.

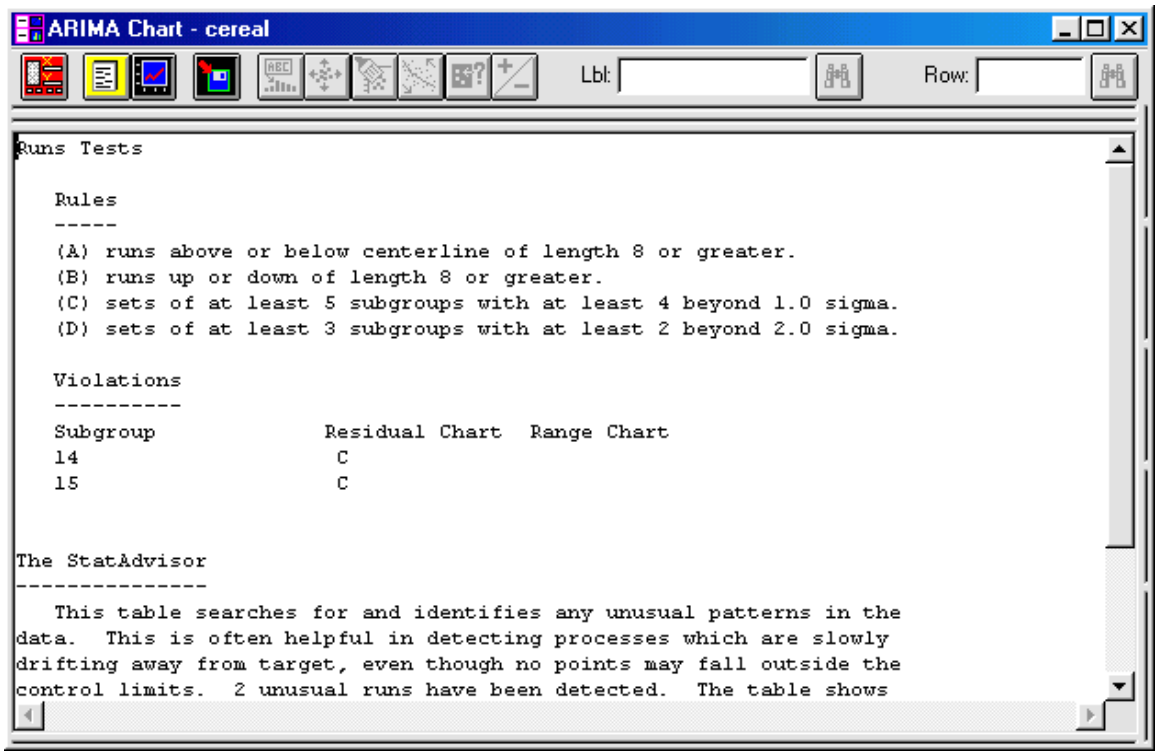


Figure 7-6. Runs Tests

The tests search for and identify any unusual patterns in the residuals, which are helpful in detecting processes that are slowly drifting away from target, even though no points may be outside the control limits. The Runs Tests table shows the subgroup or observation at which the unusual pattern was detected, as well as the particular rule that was violated. The rules are identified by letters (A, B, C, D, etc.); the subgroups or observations by numbers (1, 2, 3, 4, etc.). If the table shows Rule D in Subgroup 2 in violation, it means that rule D was violated at point 2. *For more information, see the AT&T Statistical Quality Control Handbook.*

Use the *Runs Tests Options* dialog box to choose the rules you want to include in the tests (see Figure 7-7). *See Online Help for a list of the rules and their definitions.*

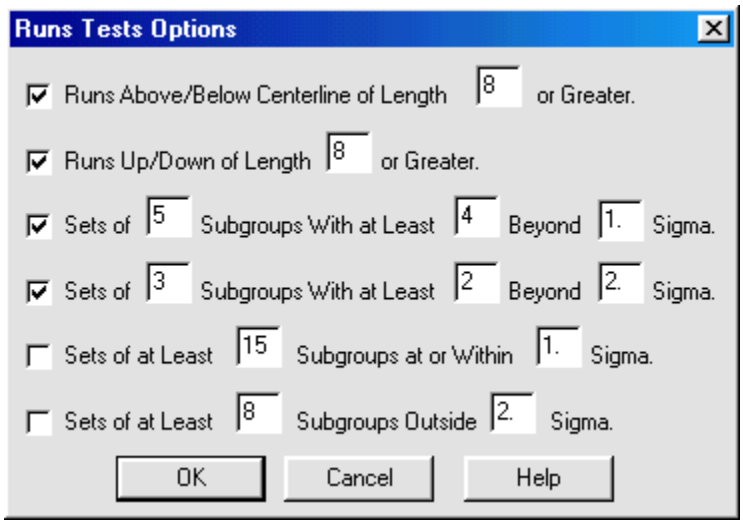


Figure 7-7. Runs Tests Options

Capability Indices

The Capability Indices option calculates several process capability indices based on the estimated process mean and standard deviation (see Figure 7-8). These indices help determine the capability of a process to produce products that must meet a quality standard. The capability indices will not be calculated until you enter values for the USL, Nominal, and LSL values on the Process Capability Indices Options dialog box.

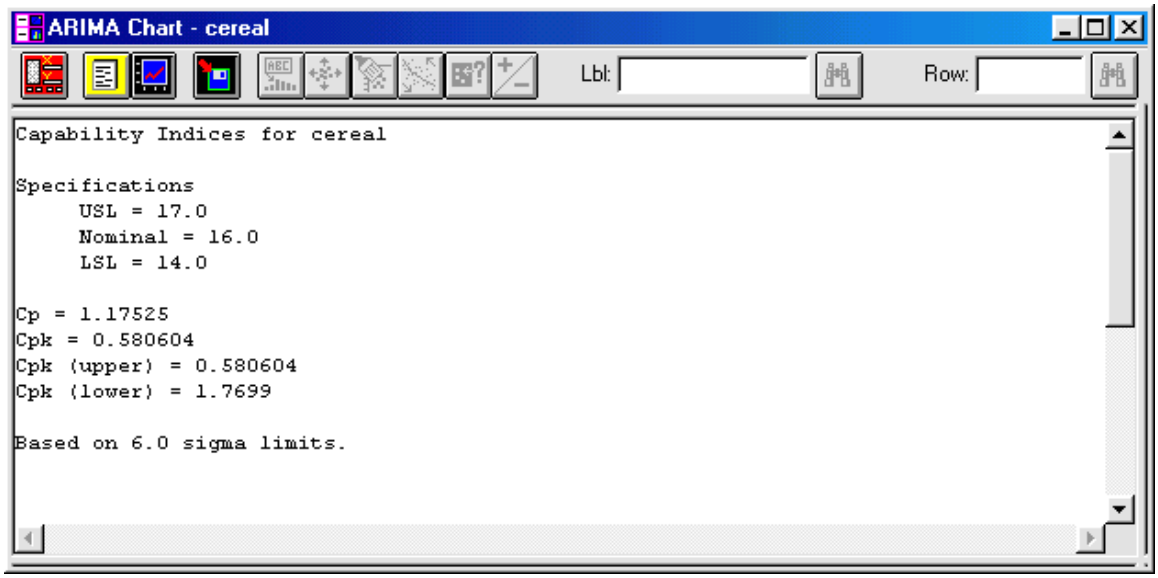


Figure 7-8. Capability Indices

Use the *Process Capability Indices Options* dialog box to choose the indices you want to include, and to enter values for the upper and lower specification limits and the target for the nominal (see Figure 7-9).

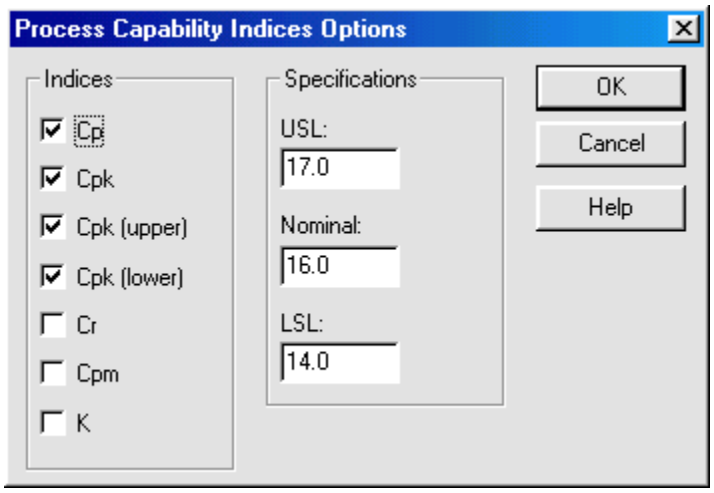


Figure 7-9. Process Capability Indices Options Dialog Box

Graphical Options

ARIMA Chart

The ARIMA Chart option creates an ARIMA Chart or a plot of the residuals for each of the subgroups and shows the points that are beyond the control limits (see Figure 7-10). The default chart plots the data with 3-sigma limits, based on the marginal distribution of the data and a constant centerline. With a moving centerline, the limits are based on the one-ahead forecast errors. The last two types of plots are a plot of the residuals from the fitted model and a plot that shows normalized residuals calculated by dividing them by the estimated white noise sigma. The plot flags points that violate the runs rules.

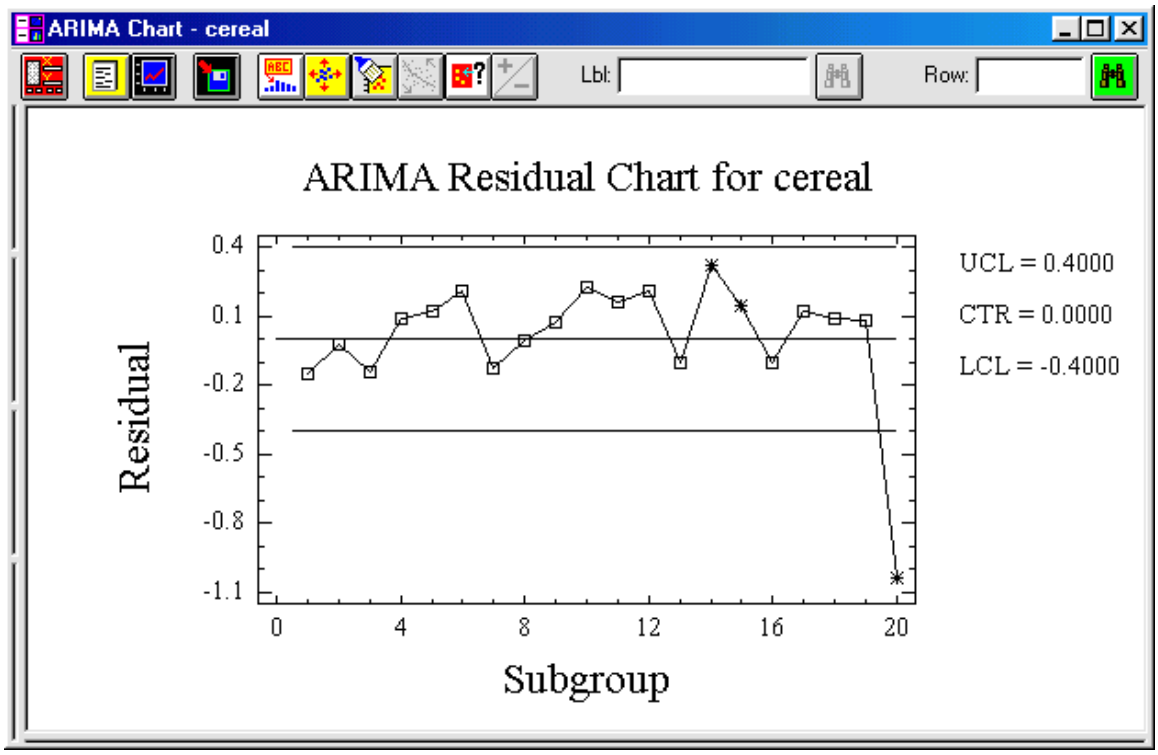


Figure 7-10. ARIMA Chart

Use the ARIMA Chart Options dialog box to choose the type of chart you want to plot. *See Figure 7-3 for an example of this dialog box.*

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; to indicate if you want the simple moving average of the subgroup statistics superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the subgroup statistics superimposed on the chart, and if so, to enter a value for lambda; and to enter the number of decimal places that will be displayed for the limits (see Figure 7-11).

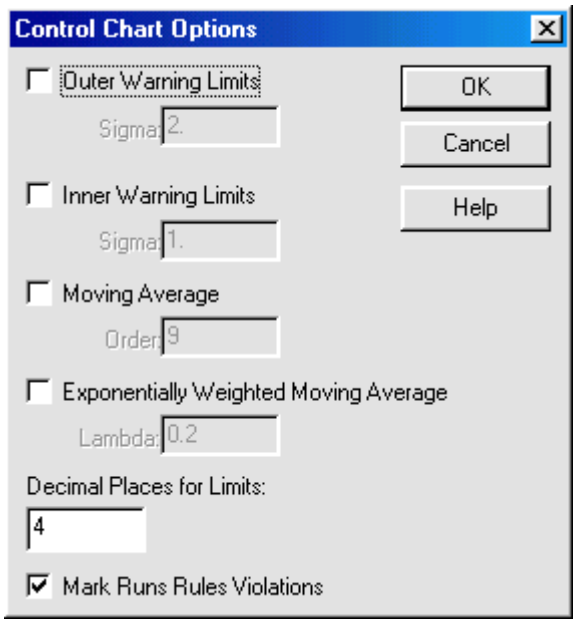


Figure 7-11. Control Chart Options Dialog Box

Range Chart

The Range Chart option creates a plot of the ranges for each of the subgroups and shows the points that are beyond the control limits (see Figure 7-12).

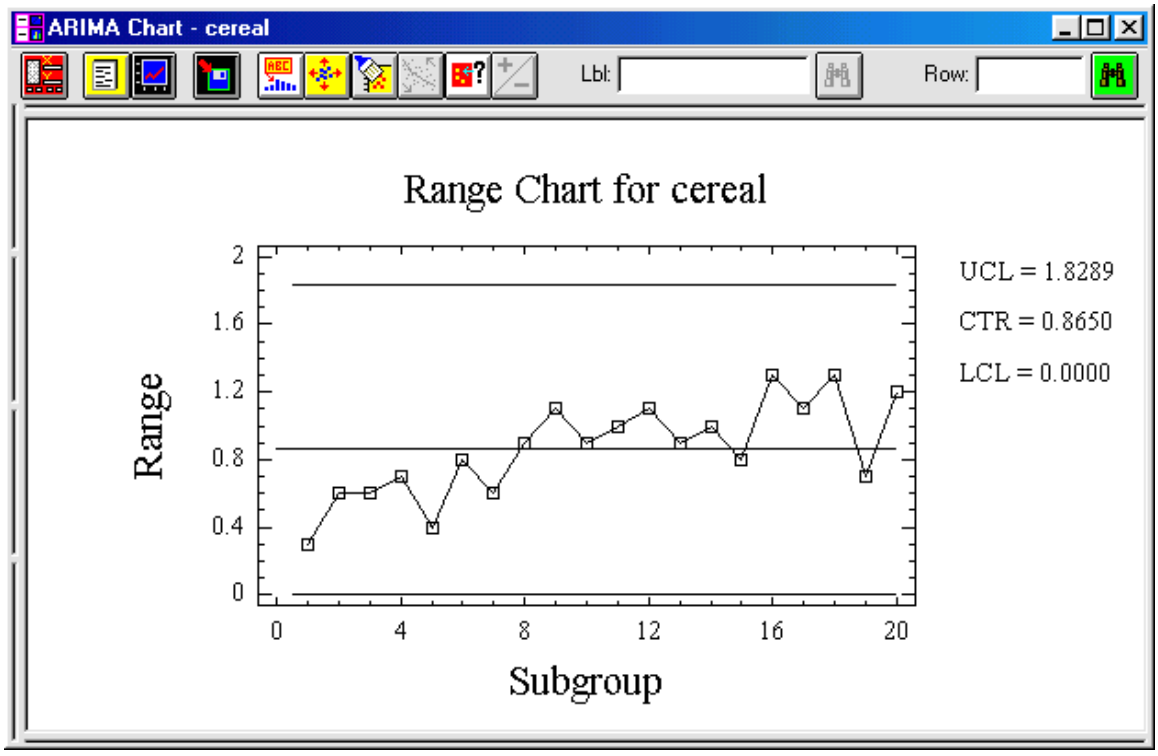


Figure 7-12. Range Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; to indicate if you want the simple moving average of the subgroup statistics superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the subgroup statistics superimposed on the chart, and if so, to enter a value for lambda; and to enter the number of decimal places that will be displayed for the limits.

Residual Autocorrelation Function Plot

The Residual Autocorrelation Function Plot option creates a plot of the estimated autocorrelations between the residuals at various lags (see Figure 7-13). The lag k autocorrelation coefficient measures the correlation between the residuals at time t and time t-k. If the probability limits at a particular lag do not contain the estimated coefficient, there is a statistically significant correlation at that lag at the given confidence level.

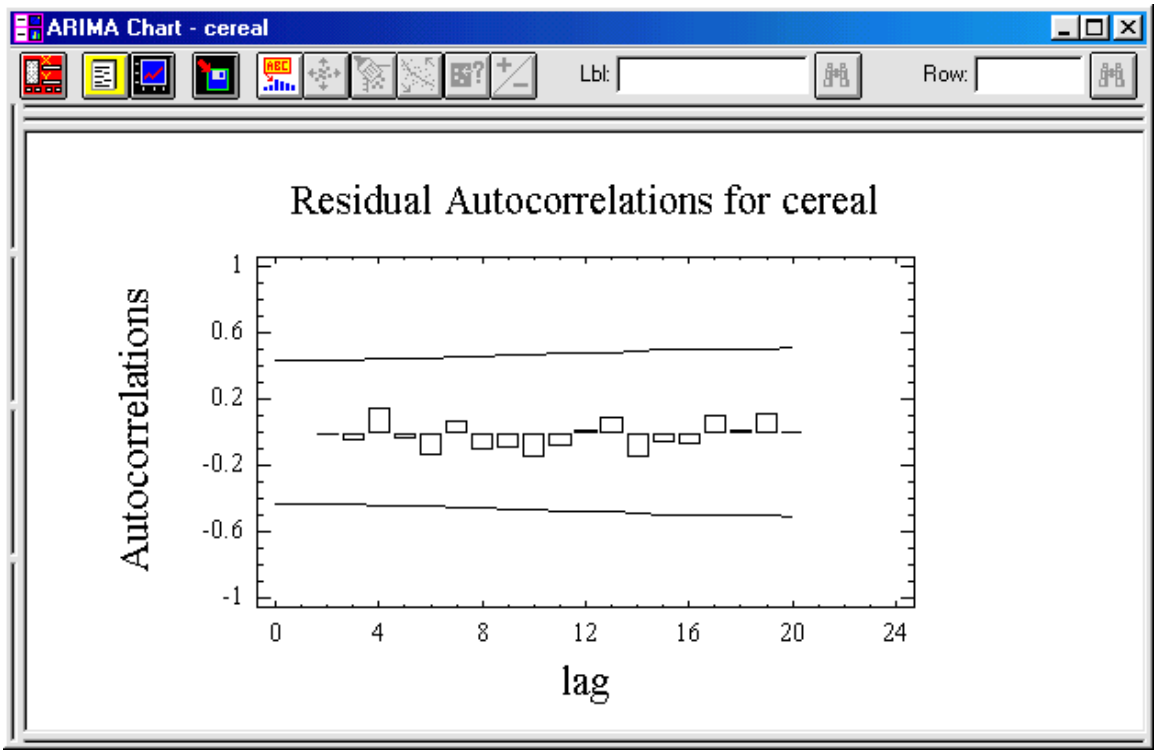


Figure 7-13. Residual Autocorrelation Function Plot

Use the *Residual Autocorrelation Function Options* dialog box to enter values for the number of lags and the confidence level (see Figure 7-14).

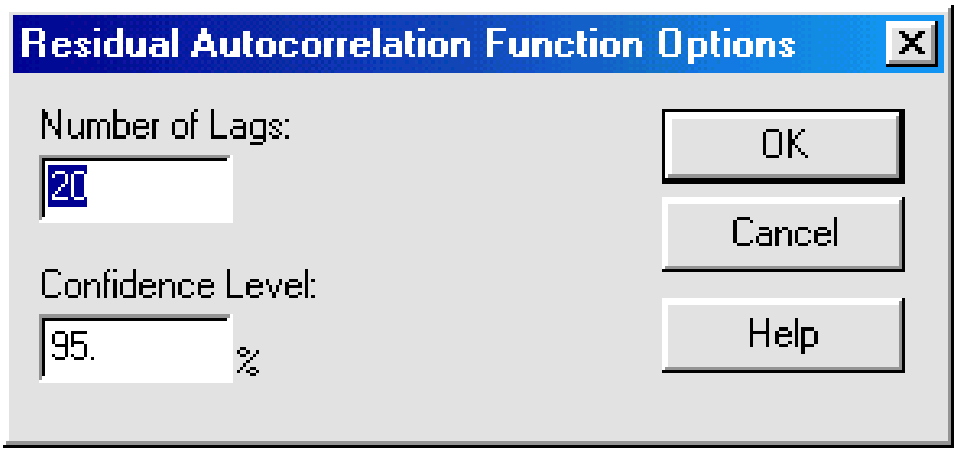


Figure 7-14. Residual Autocorrelation Function Options Dialog Box

Residual Partial Autocorrelation Function Plot

The Residual Partial Autocorrelation Function Plot option creates a plot you can use to determine the order of autoregressive model needed to fit the data (see Figure 7-15). If the probability limits at a particular lag do not contain the estimated coefficient there is a statistically significant correlation at that lag at the given confidence level.

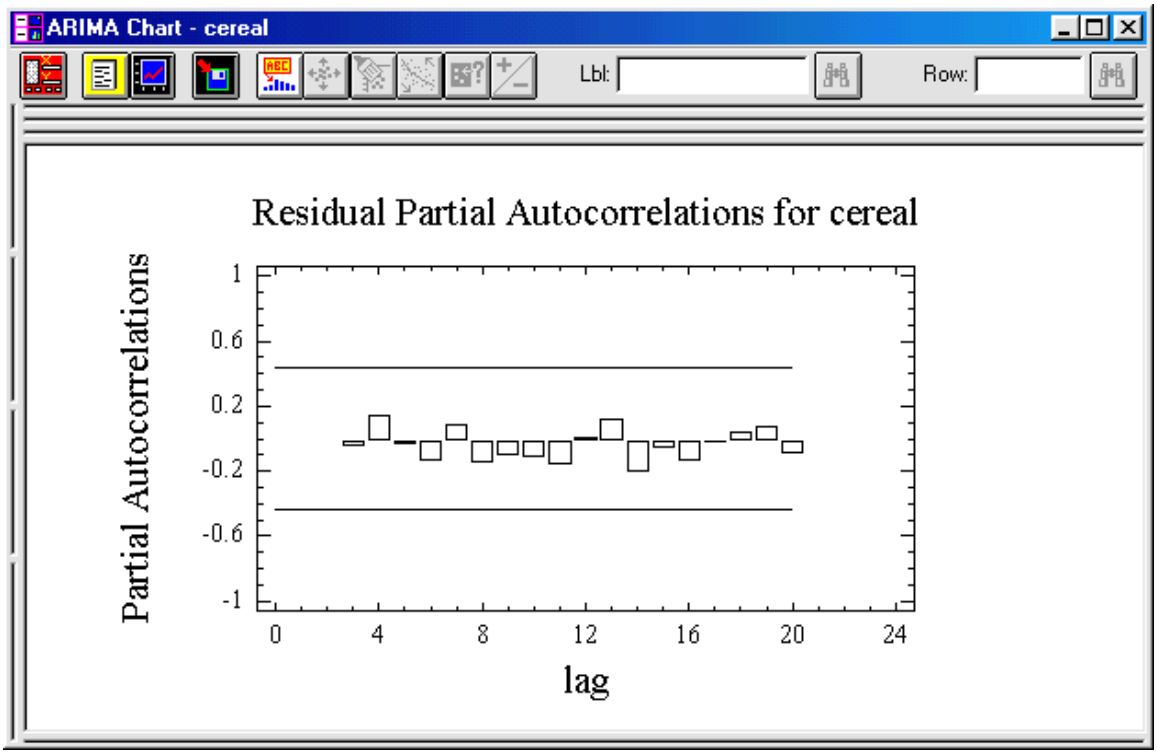


Figure 7-15. Residual Partial Autocorrelation Function Plot

Use the *Residual Partial ACF Options* dialog box to enter values for the number of lags and the confidence level. *See Figure 7-14 for an example of the Residual Autocorrelation Function Options dialog box, which is identical to this dialog box except for the title.*

Tolerance Chart (For Observations Only)

The Tolerance Chart option creates a plot of the individual values, organized by subgroup (see Figure 7-16). The horizontal line indicates the grand mean of the observations. The vertical lines indicate the subgroup ranges. Because you use this option to examine individual observations, the chart is available only when you select Observations from the Data options on the Analysis dialog box.

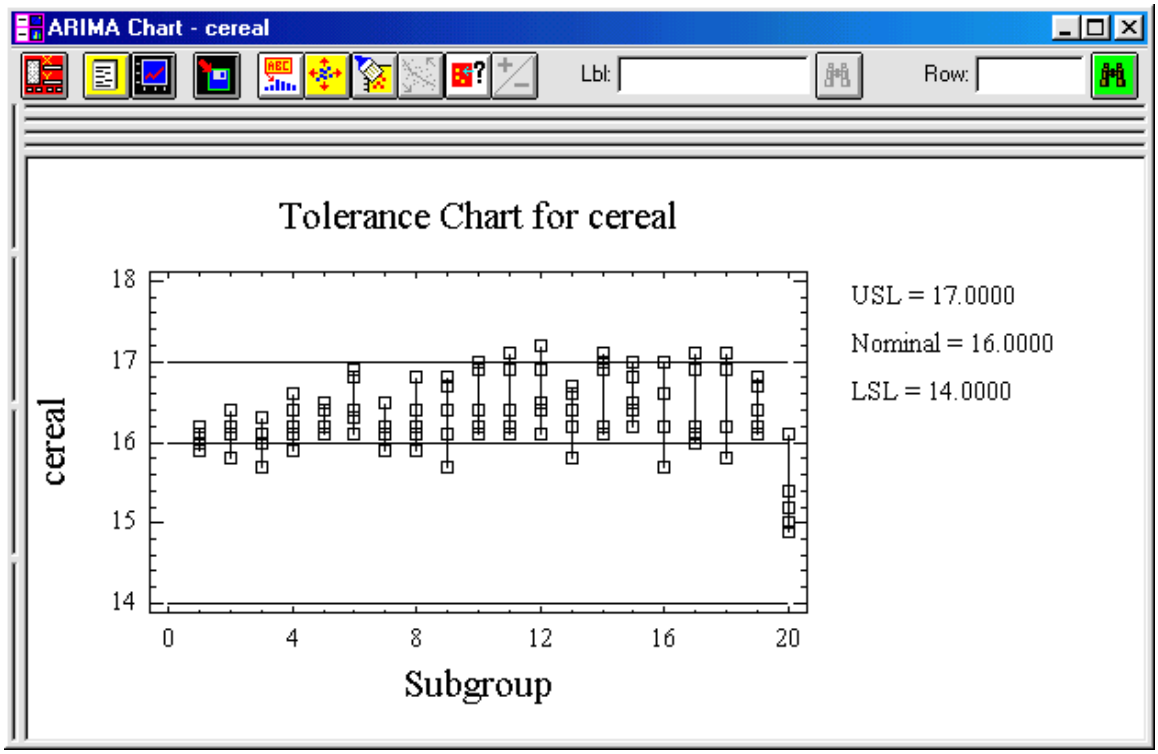


Figure 7-16. Tolerance Chart

Use the *Tolerance Chart Options* dialog box to enter values for the Upper, Nominal, and Lower specifications, to enter the number of decimal places that should be used for displaying the limits, and to indicate if points or the nominal specification line will display on the plot (see Figure 7-17).

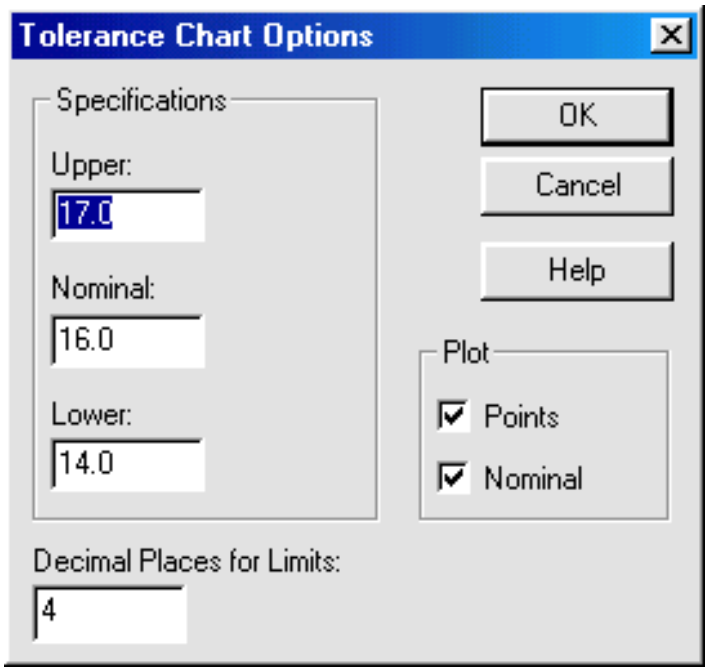


Figure 7-17. Tolerance Chart Options Dialog Box

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are seven selections: Means, Ranges, Sizes, Labels, Process Mean, Process Sigma, and Residuals.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the ARIMA Individuals Chart Analysis

Autoregressive Integrated Moving Average (ARIMA) models are a complex set of statistical techniques for time-series analysis that combines autoregressive analysis procedures with those of moving averages. A researcher, in using ARIMA models, is able to construct a trend line that accounts for both systematic error (autocorrelation) and nonsystematic (random) error.

Over the years, ARIMA models have been studied extensively. Yule first introduced Autoregressive (AR) models in 1926, Walker generalized them in 1931, and Slutzky used moving average (MA) models in 1937. Wold, however, provided the theoretical

foundations of the combined ARMA processes in 1938. Building on Wold's work, ARMA models developed in three directions:

- identification and estimation procedures (for AR, MA, and mixed ARMA processes)

- seasonal time series

- nonstationary processes (ARIMA) (Makridakis, Wheelwright, and McGee, 1983).

Box and Jenkins (1976) put together the much-needed information that was necessary to understand and use univariate time series ARIMA models. Their approach consisted of three phases: identification, estimation and testing, and application.

Many researchers, including Montgomery (1997), point out the problem of conventional control charts not working well when ". . . quality characteristics contain even low levels of correlation over time" . . . "because these control charts will give misleading results in the form of too many false alarms if the data are correlated."

Montgomery further says that an approach useful in dealing with autocorrelated data is to "directly model the correlative structure with an appropriate time-series model, use that model to remove the autocorrelation from the data, and apply control charts to the residuals."

The ARIMA and ARIMA Individuals charts analyses in STATGRAPHICS *Plus*, use Montgomery's approach. The analyses are designed to handle serially correlaed subgroup or individuals data. They also provide complete ARIMA modeling without limits on the order of autogressive or moving-average processes.

The functionality in the ARIMA Individuals Chart Analysis is identical to that in the ARIMA Chart Analysis, except you use for observations instead of subgroups.

To Access the ARIMA Individuals Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... SPECIAL PURPOSE CONTROL CHARTS... ARIMA INDIVIDUALS CHART... to display the Analysis dialog box (see Figure 7-18).

2. Complete the dialog box and click OK to display the Analysis Summary and the ARIMA Chart in the Analysis window.

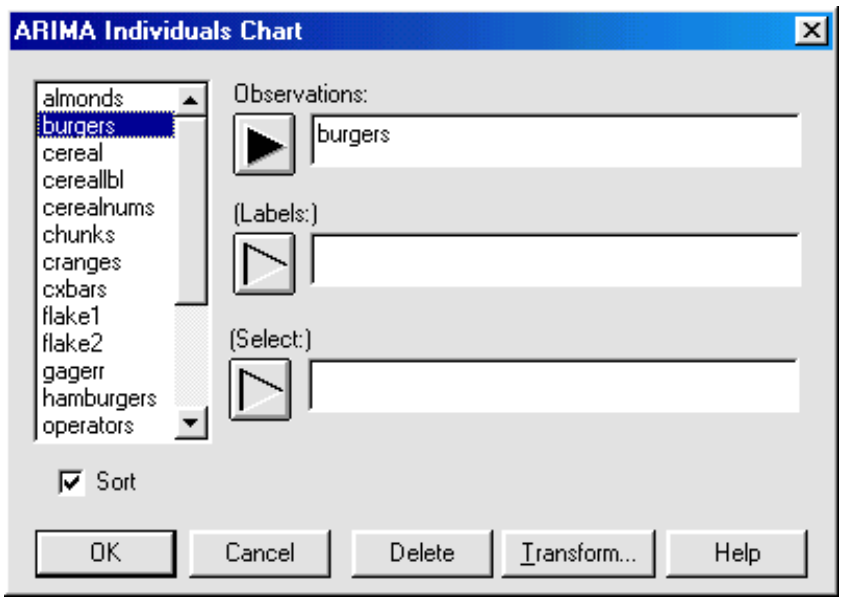


Figure 7-18. ARIMA Individuals Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 7-19). The summary shows the location of the limits on standard ARIMA and MR(2) charts. The charts are constructed using the assumption that the data come from a normal distribution with values for the mean and standard deviation estimated from the data.

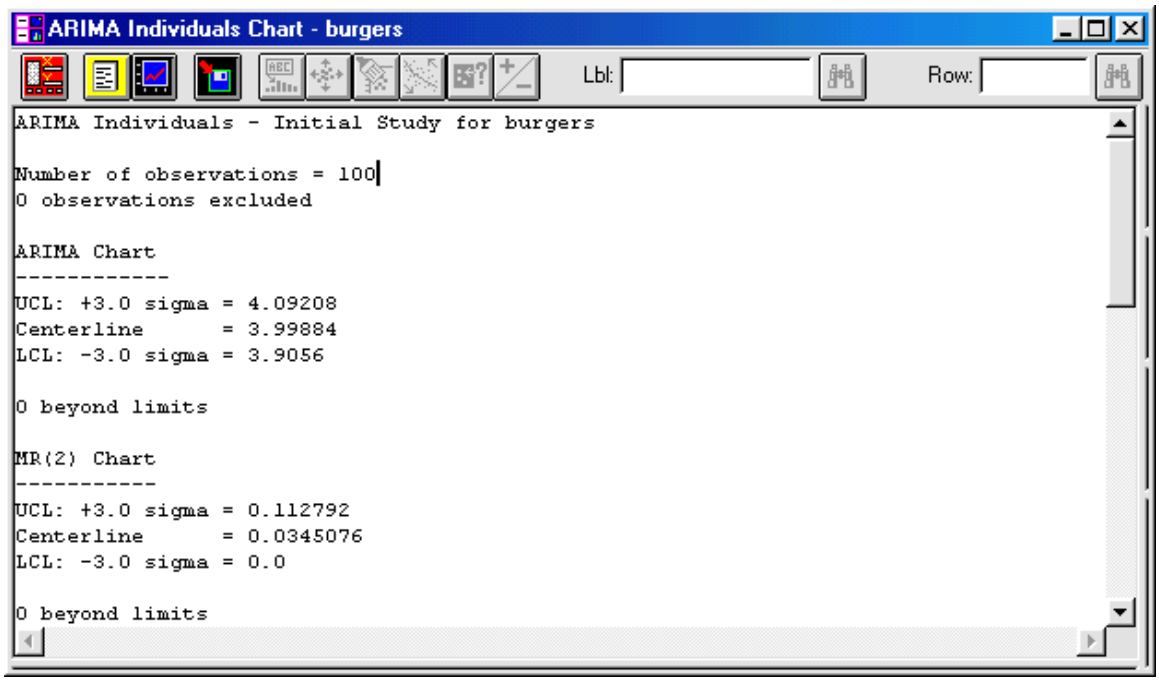


Figure 7-19. Analysis Summary

For both the ARIMA Chart and the MR(2), the report displays the values for the upper and lower control limits, the centerline, and the number of observations beyond the limits. It also shows the number of observations. It provides estimates for the process mean, process sigma, and the mean MR(2).

The ARIMA Model Summary table displays the parameters in the ARIMA model and the values of the estimated coefficients and their associated standard error, *t*-statistic, and *p*-values. The *t*-statistics and the *p*-values indicate if the coefficients are significant. For example, when testing at a 95 percent level of confidence, a coefficient with a *p*-value less than .05 is statistically significant. The table also shows if Backforecasting was used in the calculation, and provides values for the estimated white noise variance and standard deviation.

Use the *ARIMA Individuals Charts Options* dialog box to indicate if the study will be an initial or a control to standard; and to enter values for the upper and lower sigma for the ARIMA Control Limits and MR(2) Control Limits (see Figure 7-20).

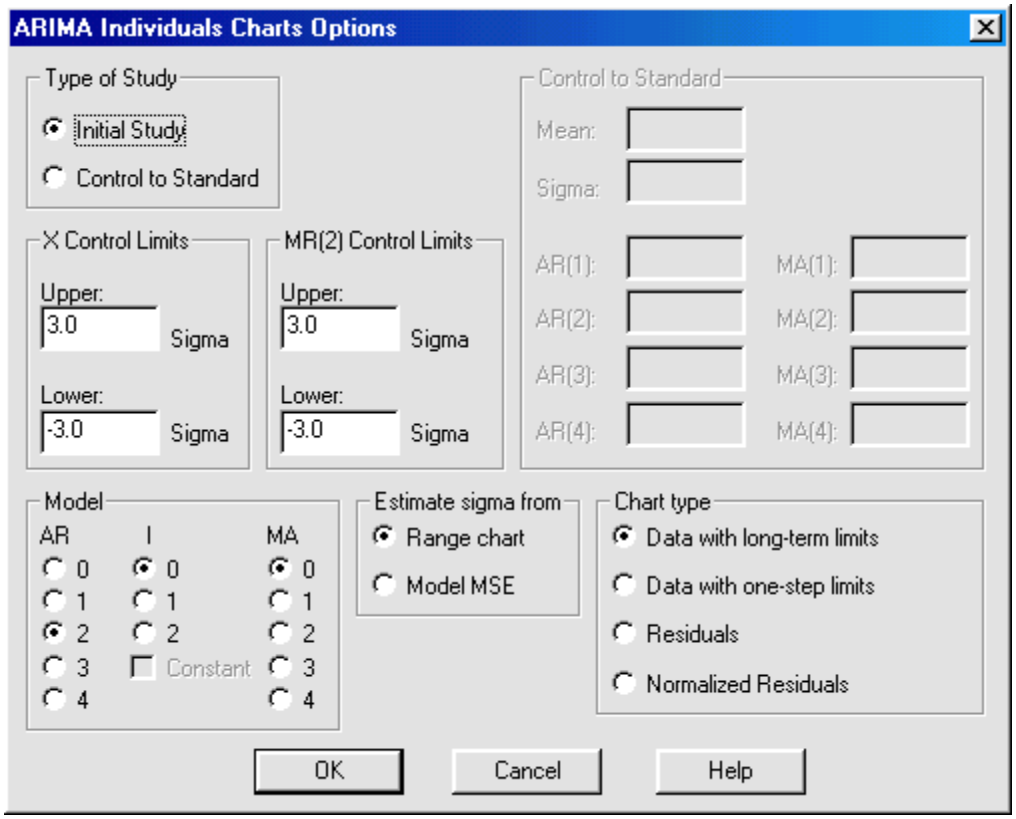


Figure 7-20. ARIMA Individuals Charts Options Dialog Box

For both types of studies, you can also choose the order of the ARIMA model, allowing for up to fourth-order AR and MA terms and up to second-order differencing. You use the Model options and choose from each of the three columns, the parameters you want estimated; that is, from the AR column, the number of nonseasonal autoregressive parameters; from the I column, the number of integrated parameters; and from the MA column, the number of nonseasonal moving-average parameters.

You can also indicate if you want sigma estimated from the MR(2) Chart or the Model MSE; and choose the type of chart you want to create: Data with long-term limits, Data with one-step limits, Residuals, or Normalized residuals.

For a Control-to-Standard Study, you can enter values for the Mean and Sigma, and for each of the AR and MA terms you choose from the Model options portion of the dialog box. *See Online Help for a complete description of each of these text boxes.*

ARIMA Individuals Chart Report

The ARIMA Individuals Chart Report option creates a report of the observations based on your selection on the ARIMA Individuals Chart Report Options dialog box (see Figure 7-21). The report shows the values that are plotted on the control chart, including the observation number, and values for X and MR(2). It notes points that are beyond the control limits with an asterisk.

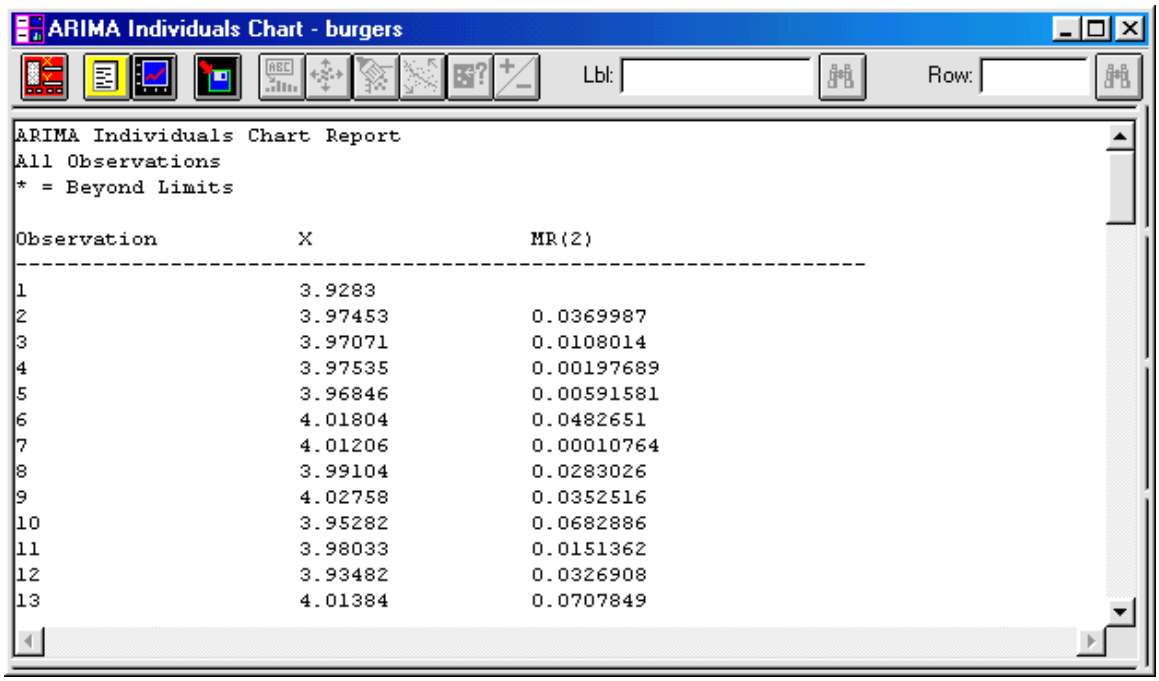


Figure 7-21. ARIMA Individuals Chart Report

Use the *ARIMA Individuals Chart Report Options* dialog box to choose the report you want to create (see Figure 7-22). You can create a report that displays all the observations; observations beyond the control limits, X′s beyond the limits, MR(2)′s beyond the limits, or observations that were excluded.

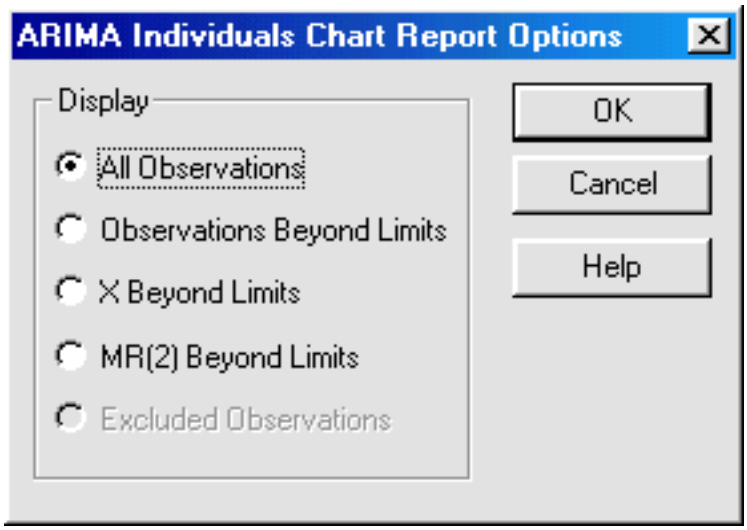


Figure 7-22. ARIMA Individuals Chart Report Options Dialog Box

Runs Tests (Available for Residuals or Normalized Residuals)

The Runs Tests option performs a battery of tests that help determine if a sequence of observations is in a nonrandom pattern, which indicates that a process is out of control (see Figure 7-23). To use this option, choose either Residuals or Normalized Residuals from the Chart Type portion of the ARIMA Individuals Chart Options dialog box.

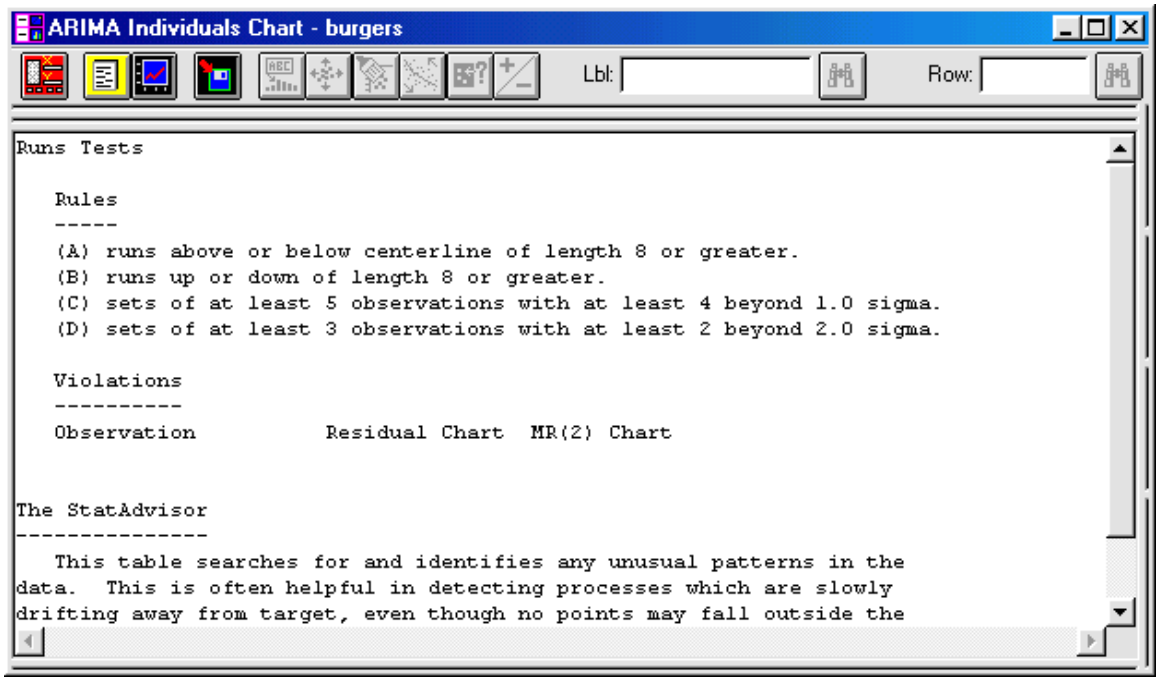


Figure 7-23. Runs Tests

The tests search for and identify any unusual patterns in the residuals, which are helpful in detecting processes that are slowly drifting away from target, even though no points may be outside the control limits. The Runs Tests table shows the subgroup or observation at which the unusual pattern was detected, as well as the particular rule that was violated. The rules are identified by letters (A, B, C, D, etc.); the subgroups or observations by numbers (1, 2, 3, 4, etc.). If the table shows Rule D in Subgroup 2 in violation, it means that rule D was violated at point 2. *For more information, see AT&T Statistical Quality Control Handbook.*

Use the *Runs Tests Options* dialog box to choose the rules you want to include in the tests. *See Online Help for a list of the rules and their definitions.*

Capability Indices

The Capability Indices option calculates several process capability indices based on the estimated process mean and standard deviation (see Figure 7-24). These indices help determine the capability of a process to produce products that must meet a quality standard. The capability indices will not be calculated until you enter values

for the USL, Nominal, and LSL values on the Process Capability Indices Options dialog box.

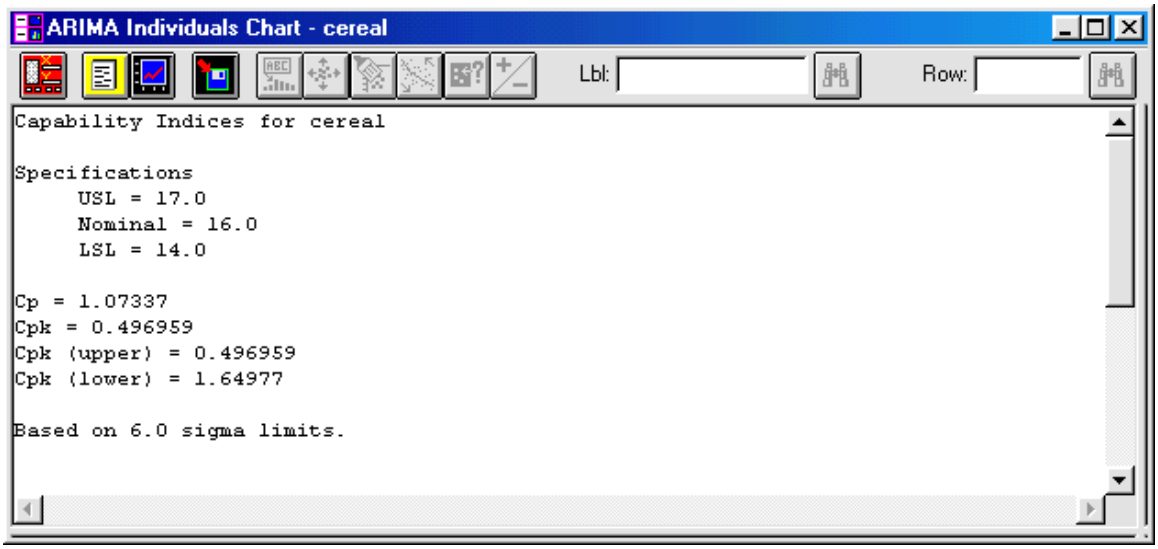


Figure 7-24. Capability Indices

Use the *Process Capability Indices Options* dialog box to choose the indices you want to include, and to enter values for the upper and lower specification limits and the target for the nominal.

Graphical Options

ARIMA Chart

The ARIMA Chart option creates an ARIMA Chart or a plot of the residuals for each of the observations and shows the points that are beyond the control limits (see Figure 7-25). The default chart plots the data with 3-sigma limits, based on the marginal distribution of the data and a constant centerline. With a moving centerline, the limits are based on the one-ahead forecast errors. The last two types of plots are a plot of the residuals from the fitted model and a plot that shows normalized residuals calculated by dividing them by the estimated white noise sigma. The plot flags points that violate the runs rules.

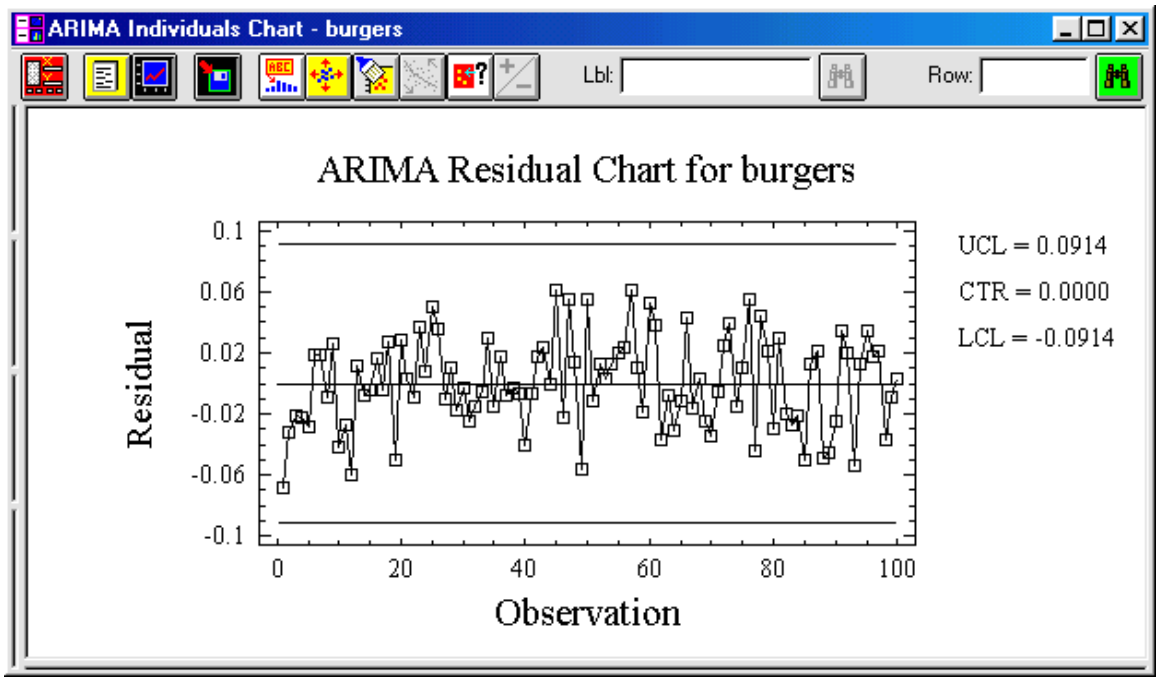


Figure 7-25. ARIMA Chart

Use the ARIMA Chart Options dialog box to choose the type of chart you want to plot.

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; to indicate if you want the simple moving average of the observations superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the observations superimposed on the chart, and if so, to enter a value for lambda; and to enter the number of decimal places that will be displayed for the limits.

MR(2) Chart

The MR(2) Chart option creates a plot of the moving ranges for each of the observations and shows the points that are beyond the control limits (see Figure 7-26).

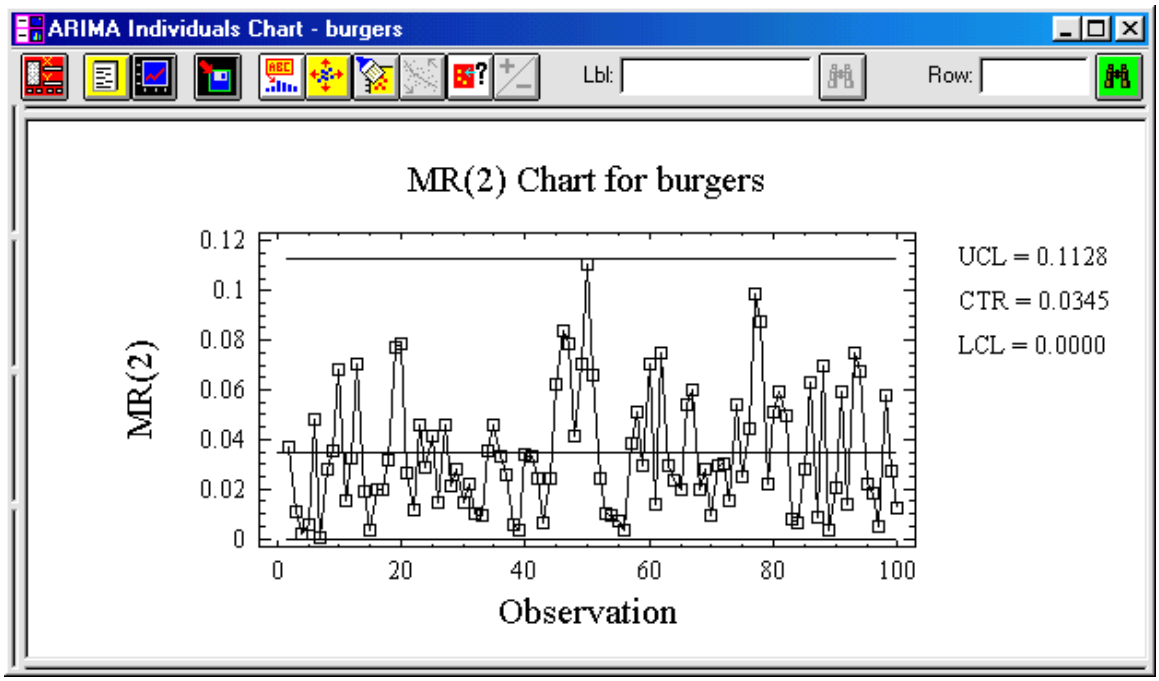


Figure 7-26. MR(2) Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot the outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; to indicate if you want the simple moving average of the observations superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the observations superimposed on the chart, and if so, to enter a value for lambda; and to enter the number of decimal places that will be displayed for the limits.

Residual Autocorrelation Function Plot

The Residual Autocorrelation Function Plot option creates a plot of the estimated autocorrelations between the residuals at various lags (see Figure 7-27). The program uses the lag k autocorrelation coefficient to measure the correlation between the residuals at time t and time t-k. If the probability limits at a particular lag do not contain the estimated coefficient there is a statistically significant correlation at that lag at the given confidence level.

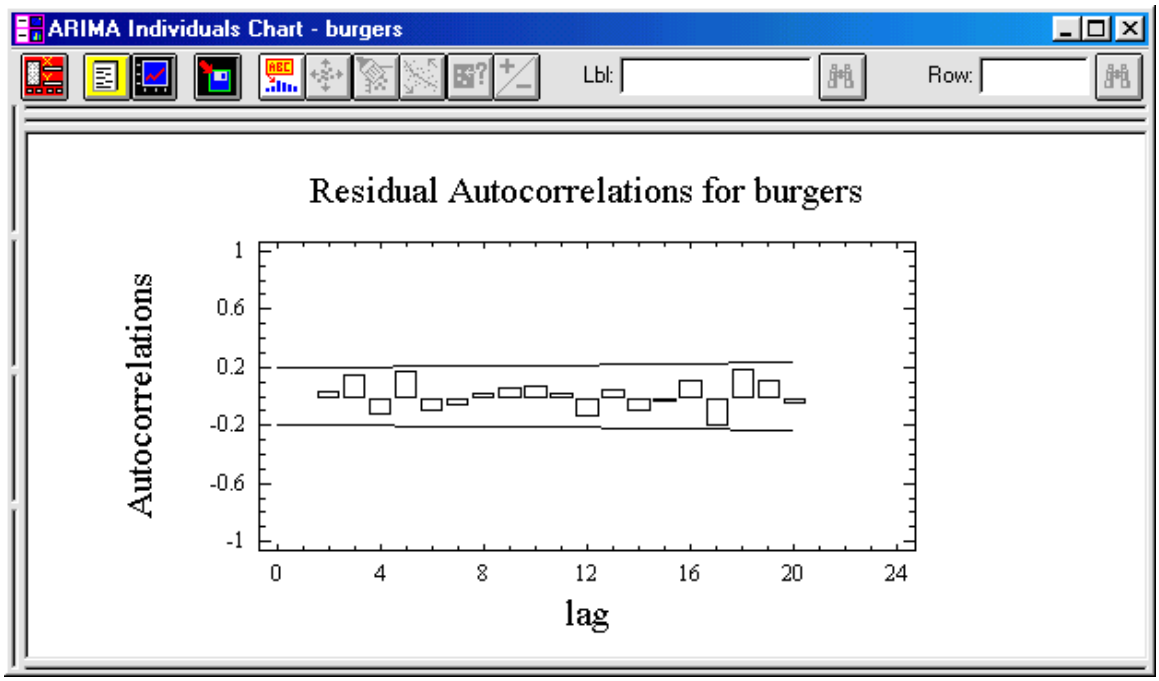


Figure 7-27. Residual Autocorrelation Function Plot

Use the *Residual Autocorrelation Function Options* dialog box to enter values for the number of lags and the confidence level (see Figure 7-28).

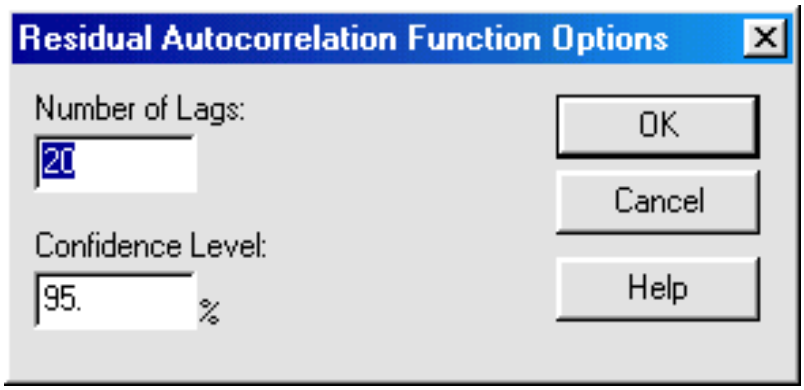


Figure 7-28. Residual Autocorrelation Function Options Dialog Box

Residual Partial Autocorrelation Function Plot

The Residual Partial Autocorrelation Function Plot option creates a plot that you can use to judge the order of autogressive model needed to fit the data (see Figure 7-29). If the probability limits at a particular lag do not contain the estimated coefficient there is a statistically significant correlation at that lag at the given confidence level.

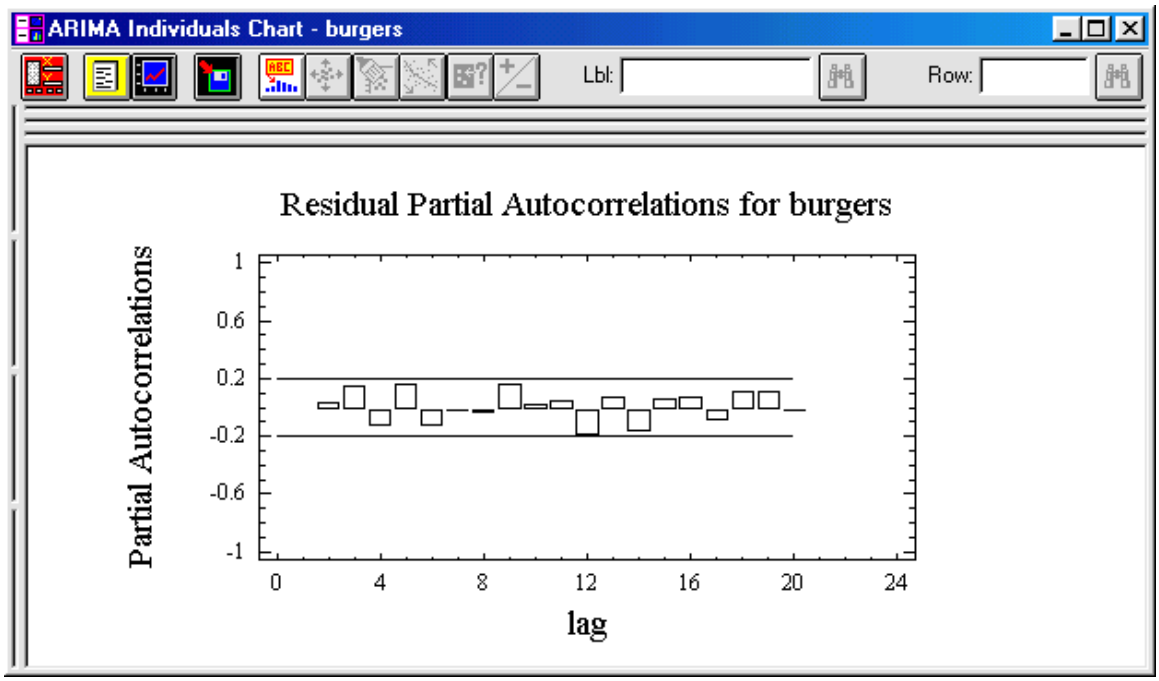


Figure 7-29. Residual Partial Autocorrelation Function Plot

Use the *Residual Partial ACF Options* dialog box to enter values for the number of lags and the confidence level. *See Figure 7-14 for an example of the Residual ACF Options dialog box, which is identical to this dialog box except for the title.*

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are six selections: Observations, Moving Ranges, Labels, Process Mean, Process Sigma, and Residuals.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the Toolwear Chart Analysis

Over the years, useful process-control techniques other than standard control charts have been developed. One production process in particular -- tool wear -- has been studied, probably because so many production processes are subjected to tool wear.

In 1990, Grant and Leavenworth found that tool wear occurred at a uniform rate over the lifetime of a tool. This type of tool wear adversely affected the average value of some dimension of the product being manufactured, therefore causing a trend. They discovered that the spread of the upper and lower specification limits was much higher than the range of the natural tolerance, which provided an adequate safety margin against producing nonconforming product as long as the machine setting held the average value somewhere near a point midway between the specification limits. However, the tendency of the value to shift rapidly due to tool wear, required many new machine setups to restore the value to the preferred position. Each new setup involved substantial costs in both idle machine time, setup expense, and possible tool replacement.

Montgomery (1997) reports research by others who confirm that adapting control charts for the tool-wear problem is a good approach. This concept calls for an initial tool setting at some multiple of sigma above the lower specification limit, while the maximum permissible process average is at the same multiple of sigma, below the upper specification limit. If the rate of wear is known or can be estimated from the data, a set of slanting control limits about the tool-wear trend can be constructed. If the sample values of X-bar fall within these limits, the tool wear is in control. When the trend line exceeds the maximum permissible process average, the process should be reset or the tool replaced.

To Access the Toolwear Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... SPECIAL PURPOSE CONTROL CHARTS... TOOLWEAR CHART... to display the Analysis dialog box (see Figure 7-30).

2. Complete the dialog box and click OK to display the Analysis Summary and the Toolwear Chart in the Analysis window.

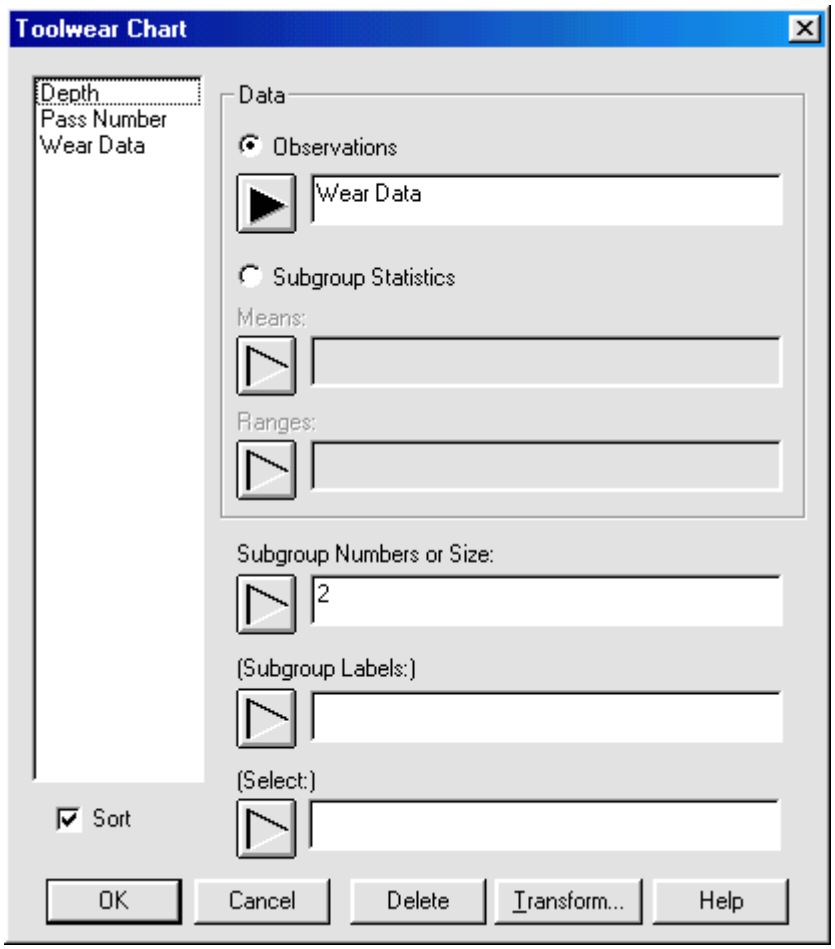


Figure 7-30. Toolwear Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 7-31). The summary shows the location of the limits on the Toolwear and Range charts. The charts are constructed using the assumption that the data come from a normal distribution with values for the mean and standard deviation estimated from the data.

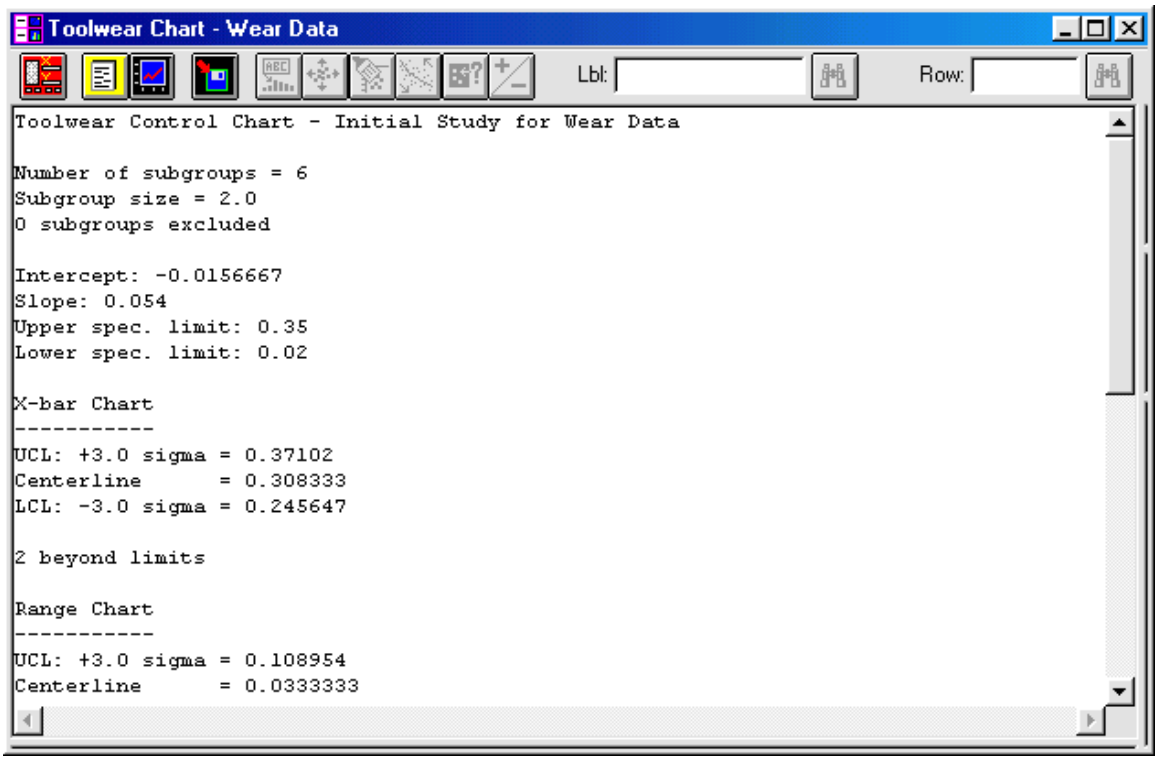


Figure 7-31. Analysis Summary

For both the Toolwear Chart and the Range Chart, the report displays the values for the upper and lower control limits, the centerline, and the number of subgroups beyond the limits. It also shows the number of subgroups, the subgroup size, and the number of subgroups excluded from the study. It provides values for the intercept, slope, USL and LSL, as well as estimates for the process mean, process sigma, and the mean range.

Use the *Toolwear Chart Options* dialog box to indicate if the study will be an initial or a control to standard; and to enter values for the upper and lower sigma for the X-bar Control Limits, Range Control Limits, and values for the Upper and Lower Specification Limits (see Figure 7-32).

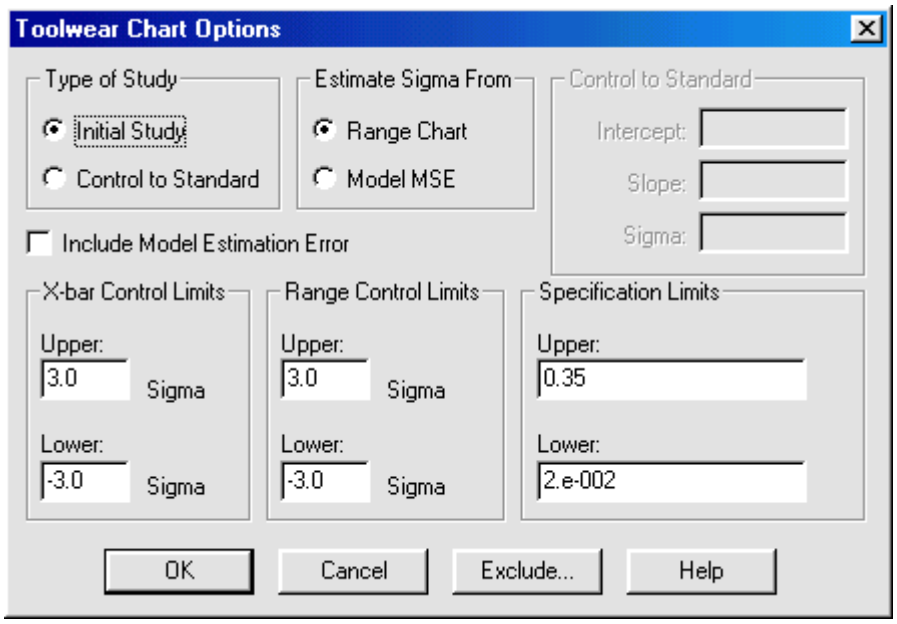


Figure 7-32. Toolwear Chart Options Dialog Box

For a Control-to-Standard Study, you can enter values for the Intercept, Slope, and Sigma. *See Online Help for a complete description of each of these text boxes.*

Use the Exclude... command on the dialog box to choose the subgroups you want to exclude from the analysis. When you click the button, the Exclude/Include Options dialog box displays.

Toolwear Chart Report

The Toolwear Chart Report option creates a report of the subgroups based on your selection on the Toolwear Chart Report Options dialog box (see Figure 7-33). The report shows the values that are plotted on the control chart, including values for the subgroup size, X-bar, and range. It notes points that are beyond the control limits with an asterisk, and points that are excluded with an X.

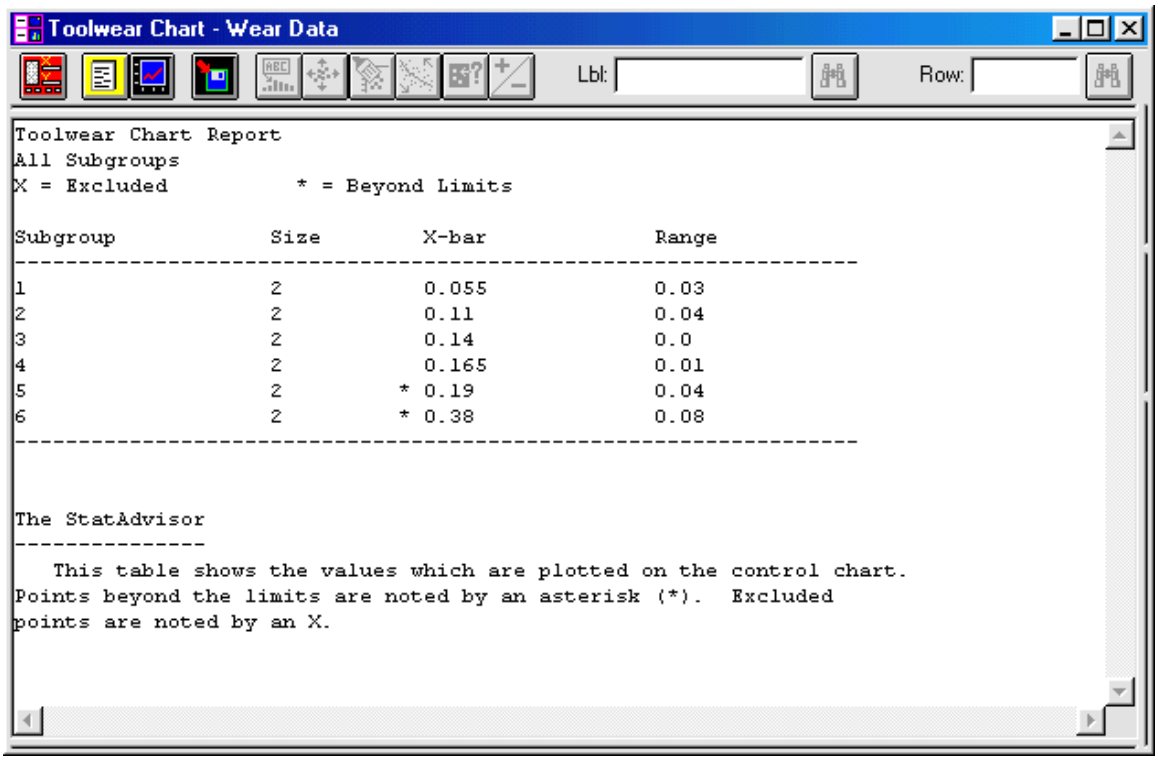


Figure 7-33. Toolwear Chart Report

Use the *Toolwear Chart Report Options* dialog box to choose the report you want to create (see Figure 7-34). You can create a report that displays all the subgroups; subgroups beyond the control limits, X-bars beyond the limits, ranges beyond the limits, or subgroups that were excluded.

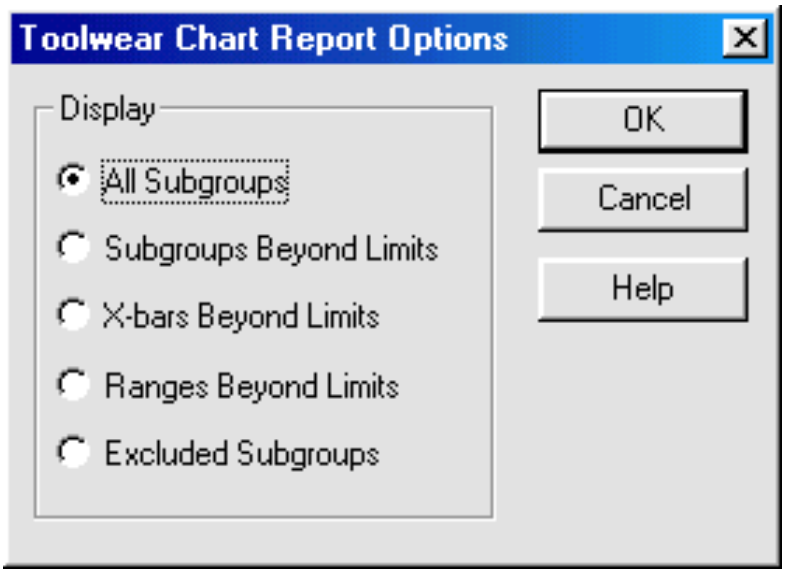


Figure 7-34. Toolwear Chart Report Options Dialog Box

Runs Tests

The Runs Tests option performs a battery of tests that help determine if a sequence of observations is in a nonrandom pattern, which indicates that a process is out of control (see Figure 7-35).

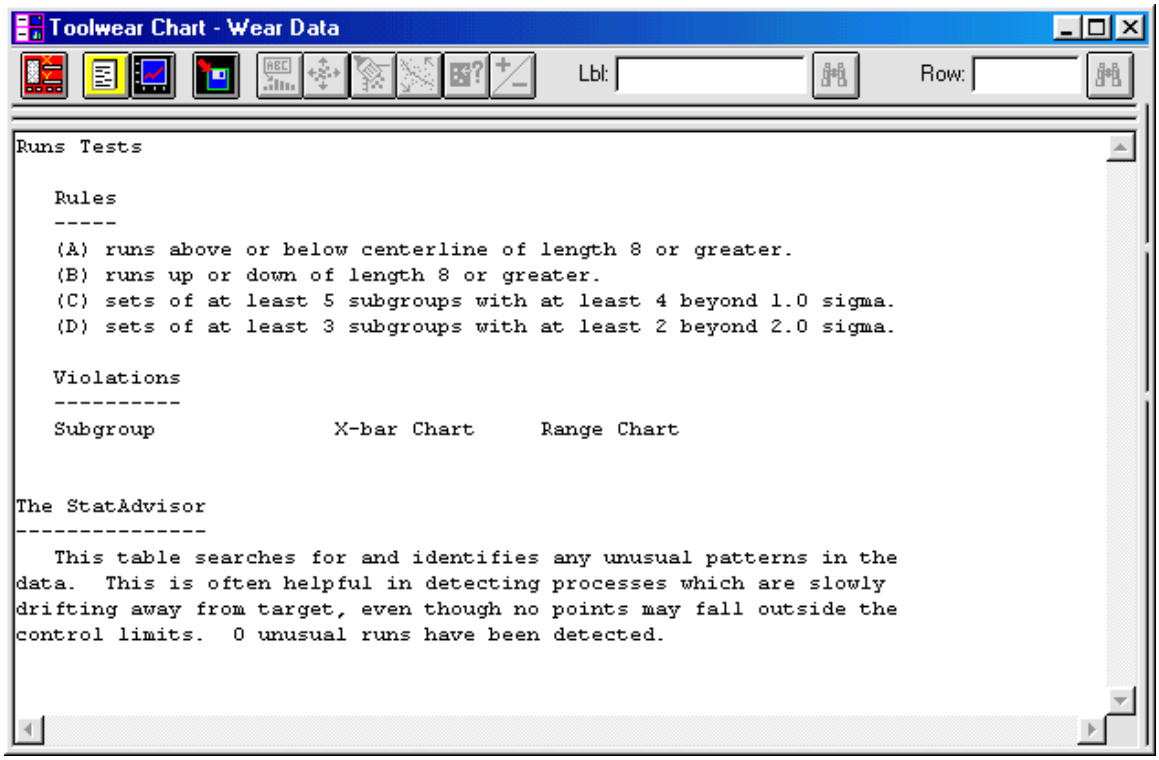


Figure 7-35. Runs Tests

The tests search for and identify any unusual patterns in the subgroup statistics, which are helpful in detecting processes that are slowly drifting away from target, even though no points may be outside the control limits. The Runs Tests table shows the subgroup at which the unusual pattern was detected, as well as the particular rule that was violated.

Use the *Runs Tests Options* dialog box to choose the rules you want to include in the tests. *See Online Help for a list of the rules and their definitions.*

Graphical Options

Toolwear Chart

The Toolwear Chart option creates a plot of the means for each of the subgroups and shows the points that are beyond the control limits (see Figure 7-36).

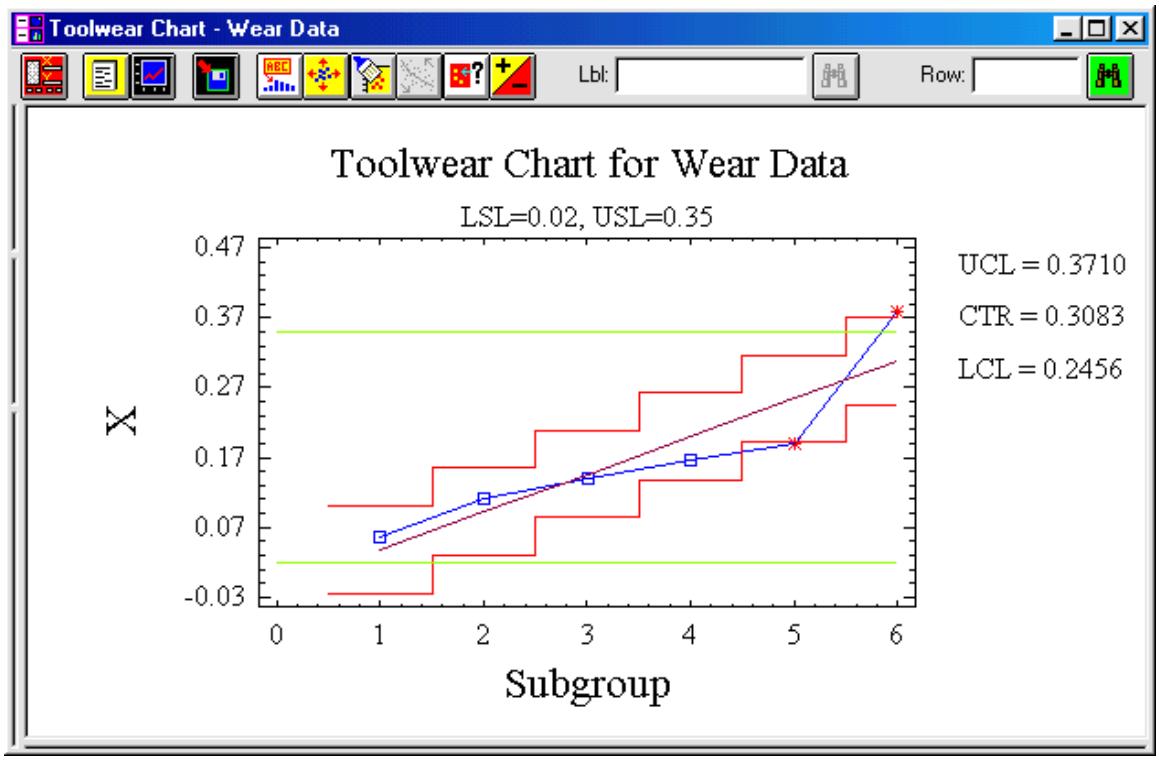


Figure 7-36. Toolwear Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; and to enter the number of decimal places that will be displayed for the limits.

Range Chart

The Range Chart option creates a plot of the ranges for each of the subgroups and shows the points that are beyond the control limits (see Figure 7-37).

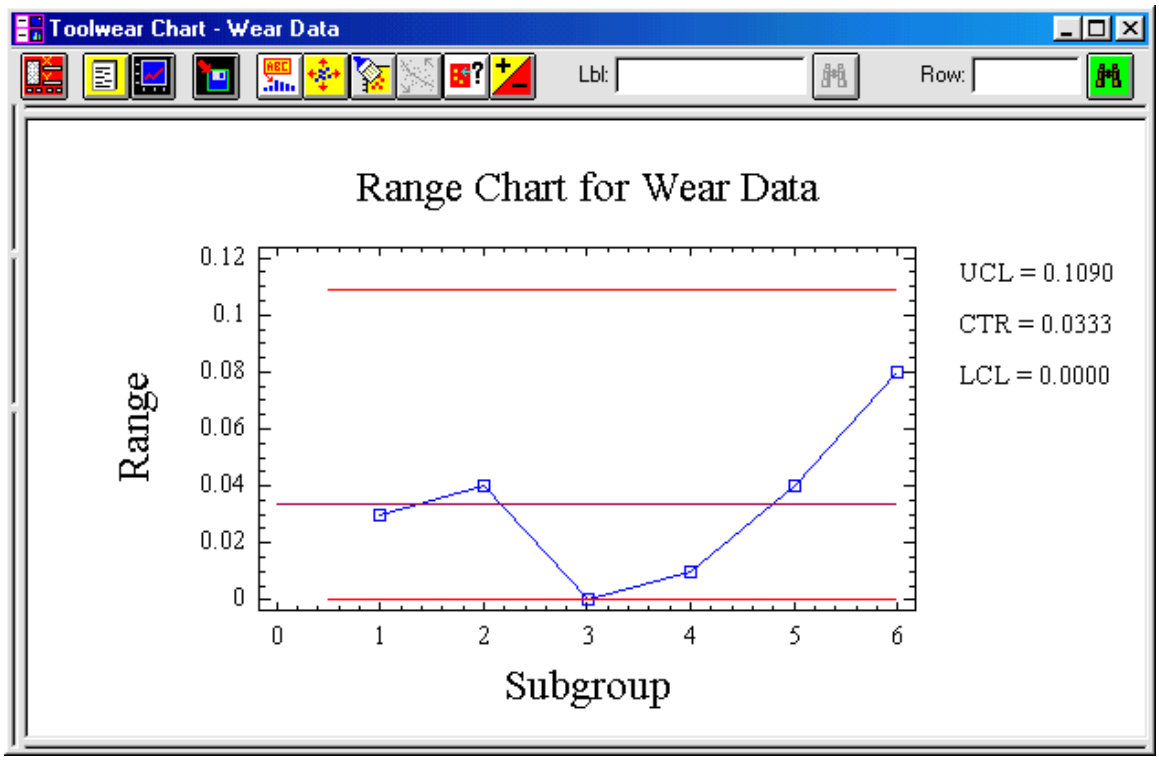


Figure 7-37. Range Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; and to enter the number of decimal places that will be displayed for the limits.

Tolerance Chart (For Observations Only)

The Tolerance Chart option creates a plot of the individual values, organized by subgroup (see Figure 7-38). The horizontal line indicates the grand mean of the observations. The vertical lines indicate the subgroup ranges. Because you use this option to examine individual observations, the chart is available only when you select Observations from the Data options on the Analysis dialog box.

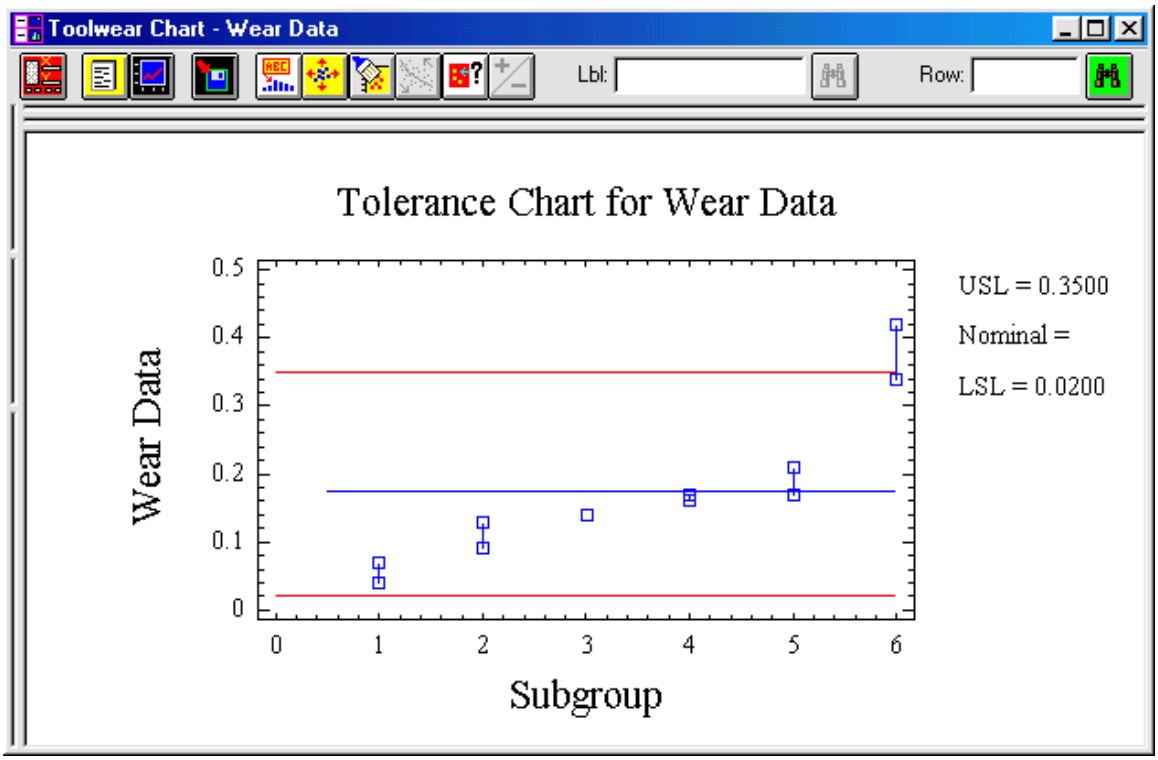


Figure 7-38. Tolerance Chart

Use the *Tolerance Chart Options* dialog box to enter a value for the Nominal specification, to enter the number of decimal places that should be used for displaying the limits, and to indicate if points or the nominal specification line will display on the plot.

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are seven selections: Means, Ranges, Sizes, Labels, Process Mean, Process Sigma, and Residuals.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the Toolwear Individuals Chart Analysis

Over the years, useful process-control techniques other than standard control charts have been developed. One production process in particular -- tool wear -- has been studied, probably because so many production processes are subjected to tool wear.

In 1990, Grant and Leavenworth found that tool wear occurred at a uniform rate over the lifetime of a tool. This type of tool wear adversely affected the average value of some dimension of the product being manufactured, therefore causing a trend. They discovered that the spread of the upper and lower specification limits was much higher than the range of the natural tolerance, which provided an adequate safety margin against producing nonconforming product as long as the machine setting held the average value somewhere near a point midway between the specification limits. However, the tendency of the value to shift rapidly due to tool wear, required many new machine setups to restore the value to the preferred position. Each new setup involved substantial costs in both idle machine time, setup expense, and possible tool replacement.

Montgomery (1997) reports research by others who confirm that adapting control charts for the tool-wear problem is a good approach. This concept calls for an initial tool setting at some multiple of sigma above the lower specification limit, while the maximum permissible process average is at the same multiple of sigma, below the upper specification limit. If the rate of wear is known or can be estimated from the data, a set of slanting control limits about the tool-wear trend can be constructed. If the sample values of X-bar fall within these limits, the tool wear is in control. When the trend line exceeds the maximum permissible process average, the process should be reset or the tool replaced.

The functionality in the Toolwear Individuals Chart Analysis is identical to that in the Toolwear Chart Analysis, except that you use observations instead of subgroups.

To Access the Toolwear Individuals Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... SPECIAL PURPOSE CONTROL CHARTS... TOOLWEAR INDIVIDUALS CHART... to display the Analysis dialog box (see Figure 7-39).

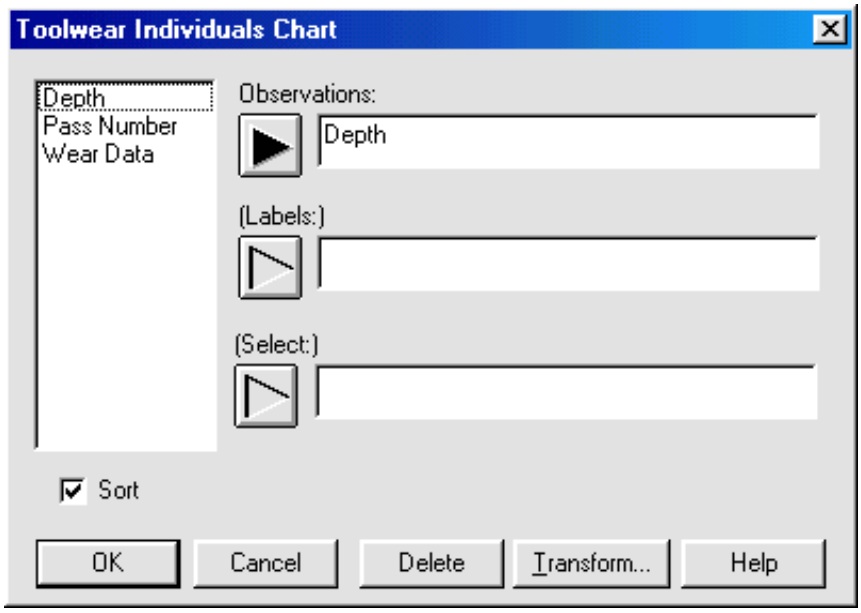


Figure 7-39. Toolwear Individuals Chart Analysis Dialog Box

2. Complete the dialog box and click OK to display the Analysis Summary and the Toolwear Chart in the Analysis window.

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 7-40). The summary shows the location of the limits on the Toolwear and MR(2) charts. The charts are constructed using the assumption that the data come from a normal distribution with values for the mean and standard deviation estimated from the data.

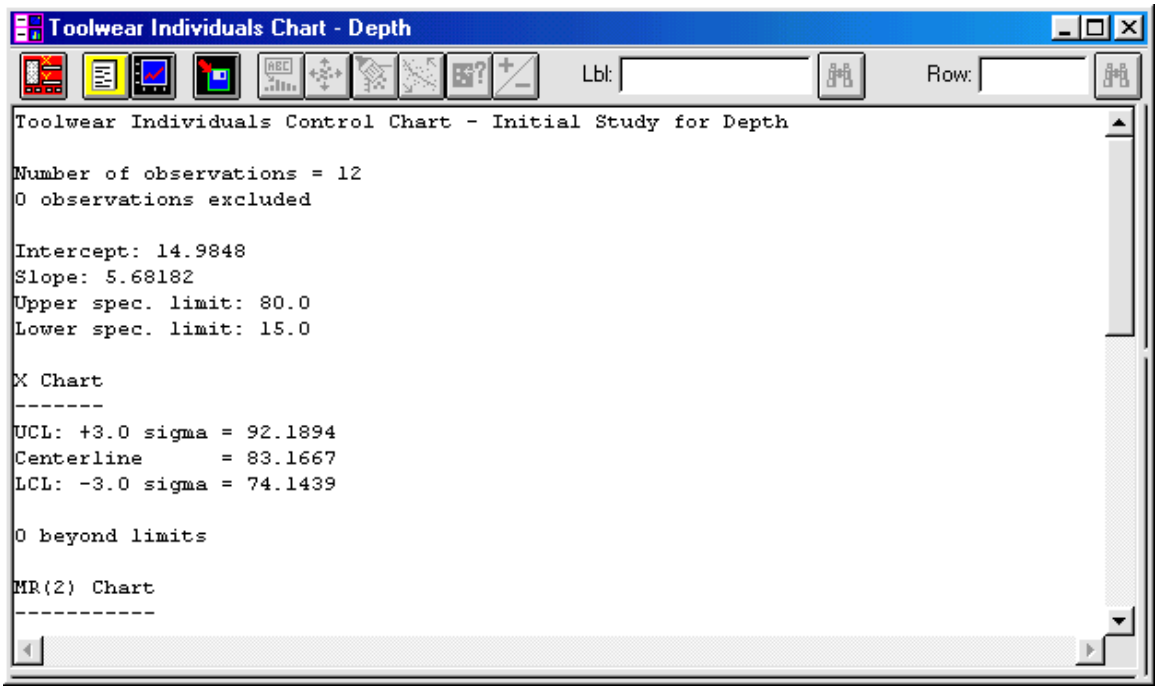


Figure 7-40. Analysis Summary

For both the Toolwear Chart and the MR(2) Chart, the report displays the values for the upper and lower control limits, the centerline, and the number of observations beyond the limits. It also shows the number of observations, and the number of observations excluded from the study. It provides values for the intercept, slope, USL and LSL, as well as estimates for the process mean, process sigma, and the mean MR(2).

Use the *Toolwear Individuals Chart Options* dialog box to indicate if the study will be an initial or a control to standard; and to enter values for the upper and lower sigma for the X Control Limits, MR(2) Control Limits, and values for the Upper and Lower Specification Limits (see Figure 7-41).

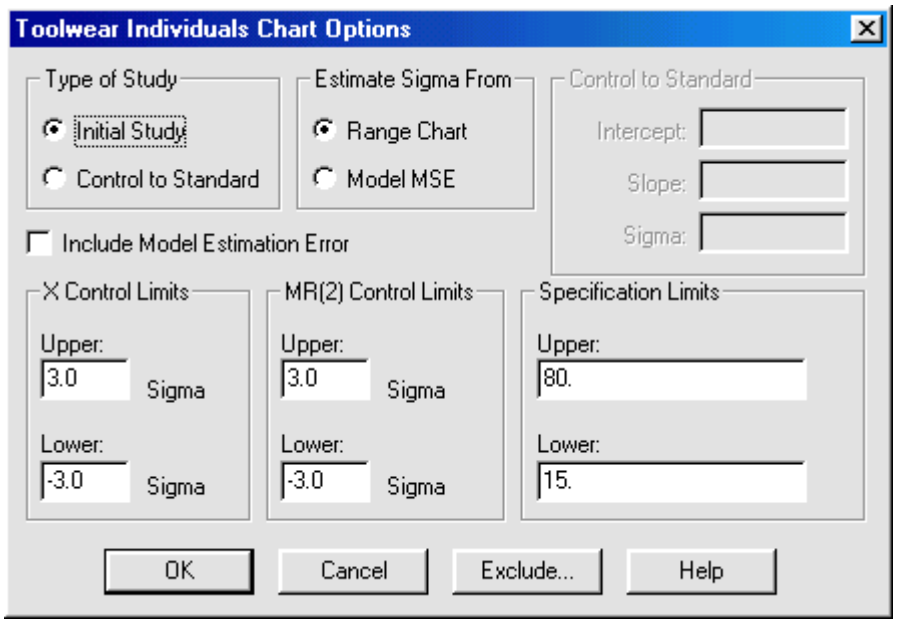


Figure 7-41. Toolwear Individuals Chart Options Dialog Box

For a Control-to-Standard Study, you can enter values for the Intercept, Slope, and Sigma. *See Online Help for a complete description of each of these text boxes.*

Use the Exclude... command on the dialog box to choose the subgroups you want to exclude from the analysis. When you click the button, the Exclude/Include Options dialog box displays.

Toolwear Individuals Chart Report

The Toolwear Individuals Chart Report option creates a report of the observations based on your selection on the Toolwear Individuals Chart Report Options dialog box (see Figure 7-42). The report notes the observation number, and shows the values that are plotted on the control chart, including values for X and MR(2). It notes points that are beyond the control limits with an asterisk, and points that are excluded with an X.

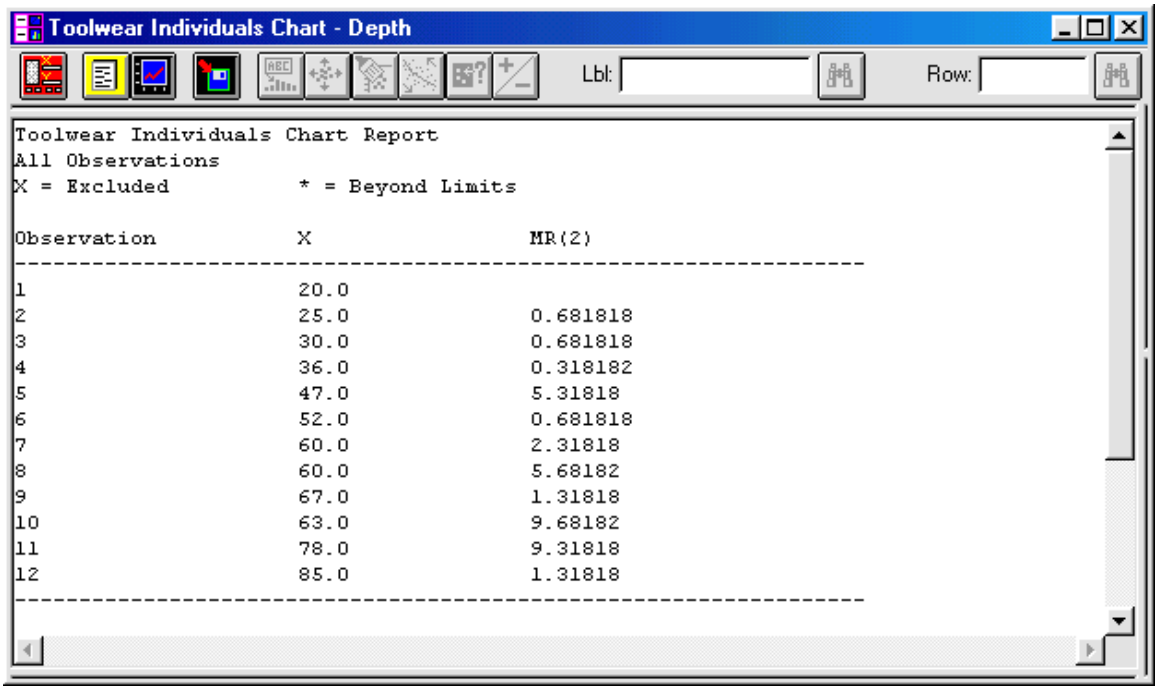


Figure 7-42. Toolwear Individuals Chart Report

Use the *Toolwear Individuals Chart Report Options* dialog box to choose the report you want to create (see Figure 7-43). You can create a report that displays all the observations; observations beyond the control limits, X′s beyond the limits, MR(2)′s beyond the limits, or observations that were excluded.

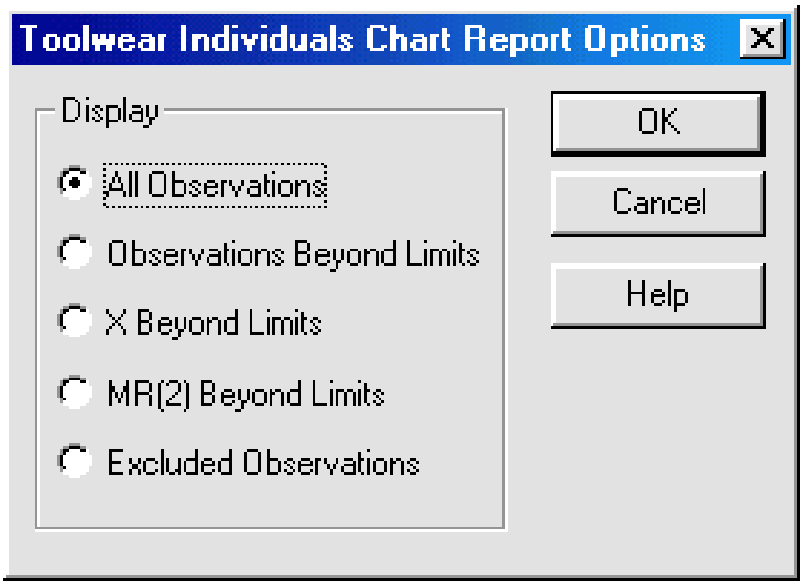


Figure 7-43. Toolwear Individuals Chart Report Options Dialog Box

Runs Tests

The Runs Tests option performs a battery of tests that help determine if a sequence of observations is in a nonrandom pattern, which indicates that a process is out of control (see Figure 7-44).

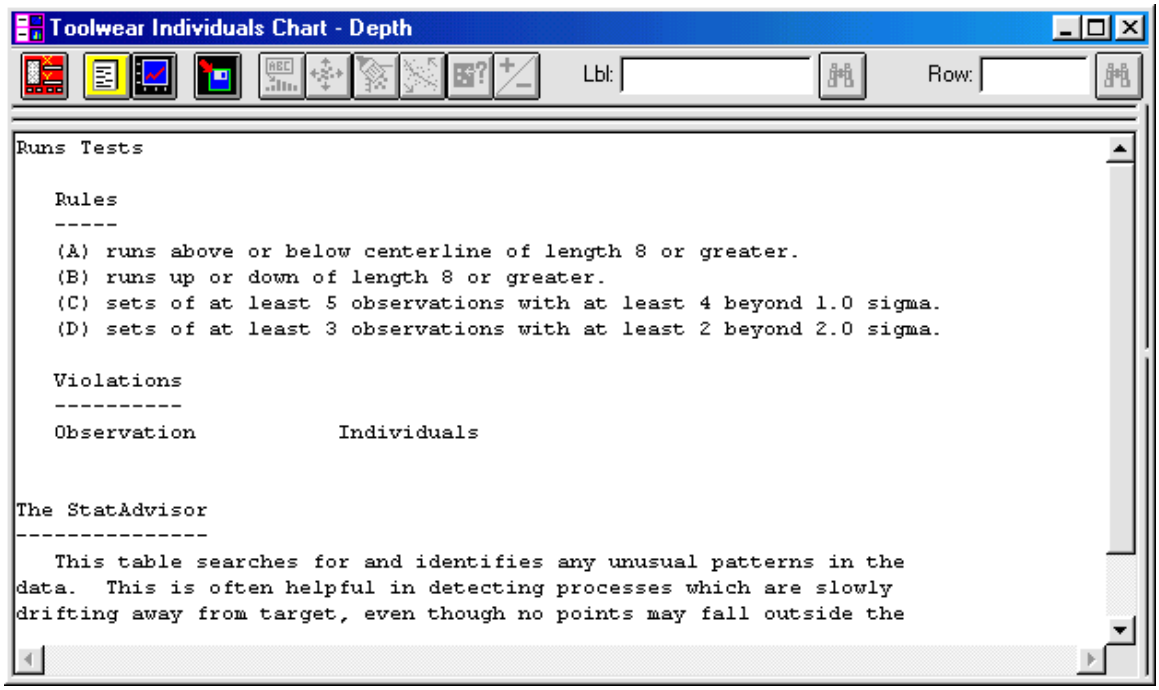


Figure 7-44. Runs Tests

The tests search for and identify any unusual patterns in the observations, which are helpful in detecting processes that are slowly drifting away from target, even though no points may be outside the control limits. The Runs Tests table shows the observation at which the unusual pattern was detected, as well as the particular rule that was violated.

Use the *Runs Tests Options* dialog box to choose the rules you want to include in the tests. *See Online Help for a list of the rules and their definitions.*

Graphical Options

Toolwear Chart

The Toolwear Chart option creates a plot of the individual measurements and shows the points that are beyond the control limits (see Figure 7-45).

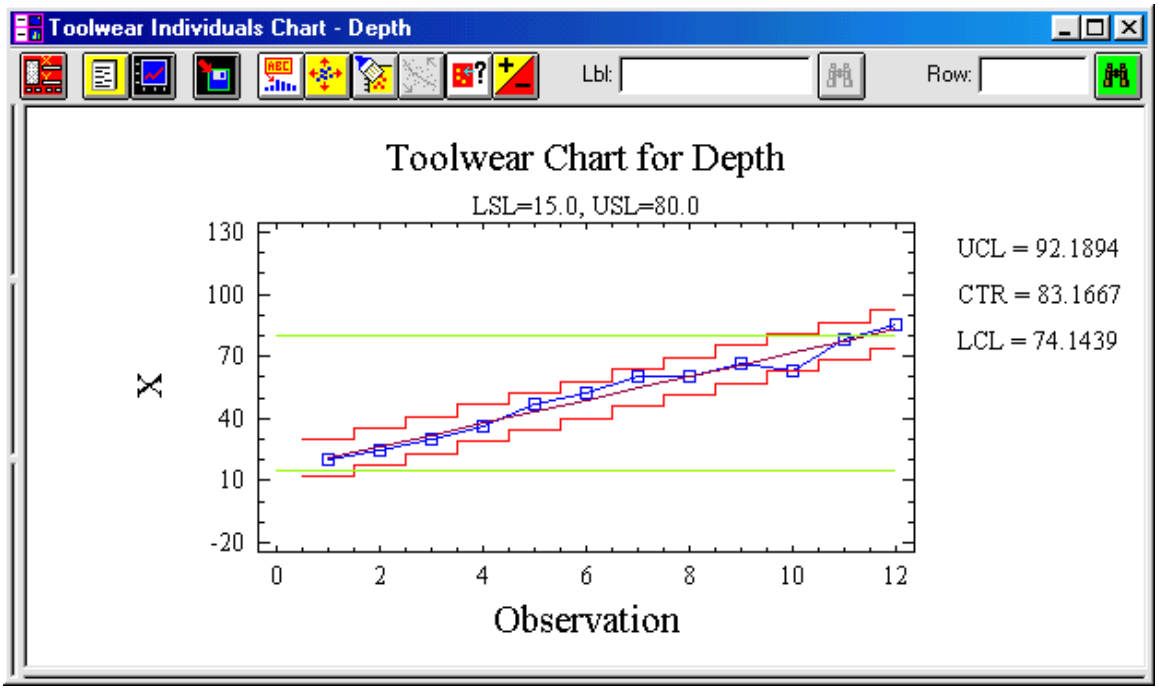


Figure 7-45. Toolwear Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; and to enter the number of decimal places that will be displayed for the limits.

MR(2) Chart

The MR(2) Chart option creates a plot of the moving ranges for each of the observations and shows the points that are beyond the control limits (see Figure 7-46).

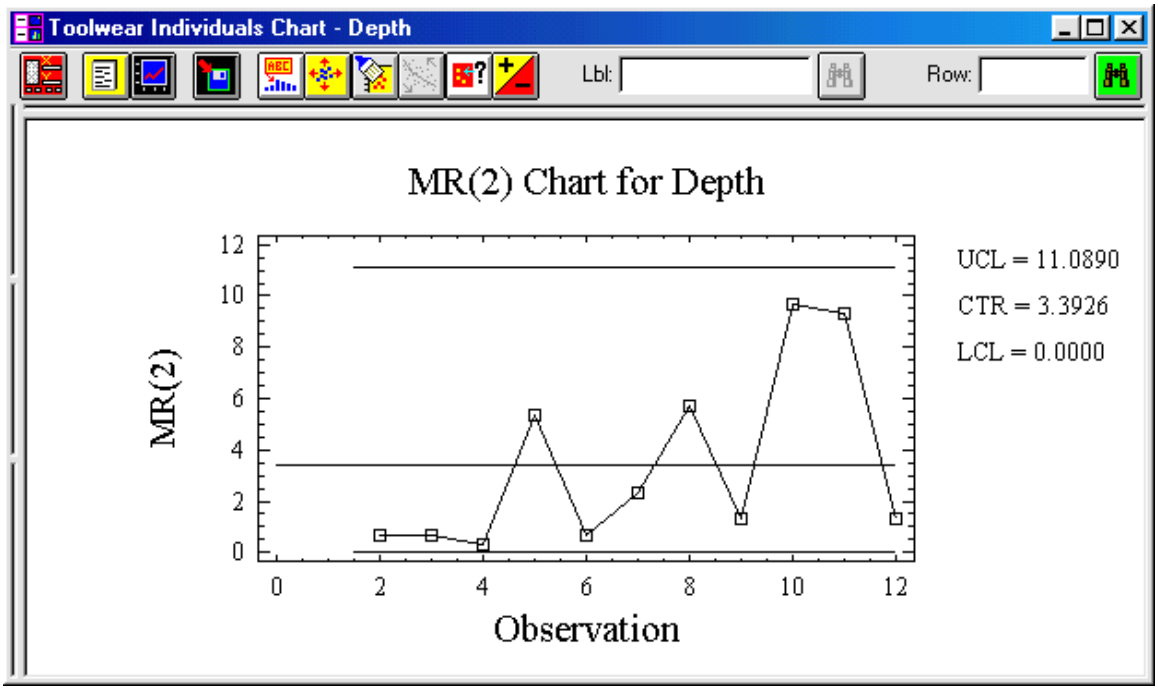


Figure 7-46. MR(2) Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; and if so, to enter a value for lambda; and to enter the number of decimal places that will be displayed for in the limits.

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are seven selections: Observations, Moving Ranges, Labels, Process Mean, Process Sigma, Included Observations, and Residuals.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the Acceptance Chart Analysis

Acceptance charts are one of two methods used for relaxing the level of surveillance provided by a standard control chart (Montgomery, 1997). The purpose of the analysis is to monitor processes that tend to operate well within process

specifications (with high C_p). Rather than place the control limits at +/- 3 sigma from the centerline, STATGRAPHICS *Plus* places them relative to the specification limits. This allows the process to drift around the centerline, while still ensuring that little if any product is out of specification.

The basis of the Acceptance Chart is controlling both the risk of rejecting a satisfactory process (α-risk), and the risk of accepting an unsatisfactory process (β-risk).

To Access the Acceptance Control Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... SPECIAL PURPOSE CONTROL CHARTS... ACCEPTANCE CHART... to display the dialog box shown in Figure 7-47.

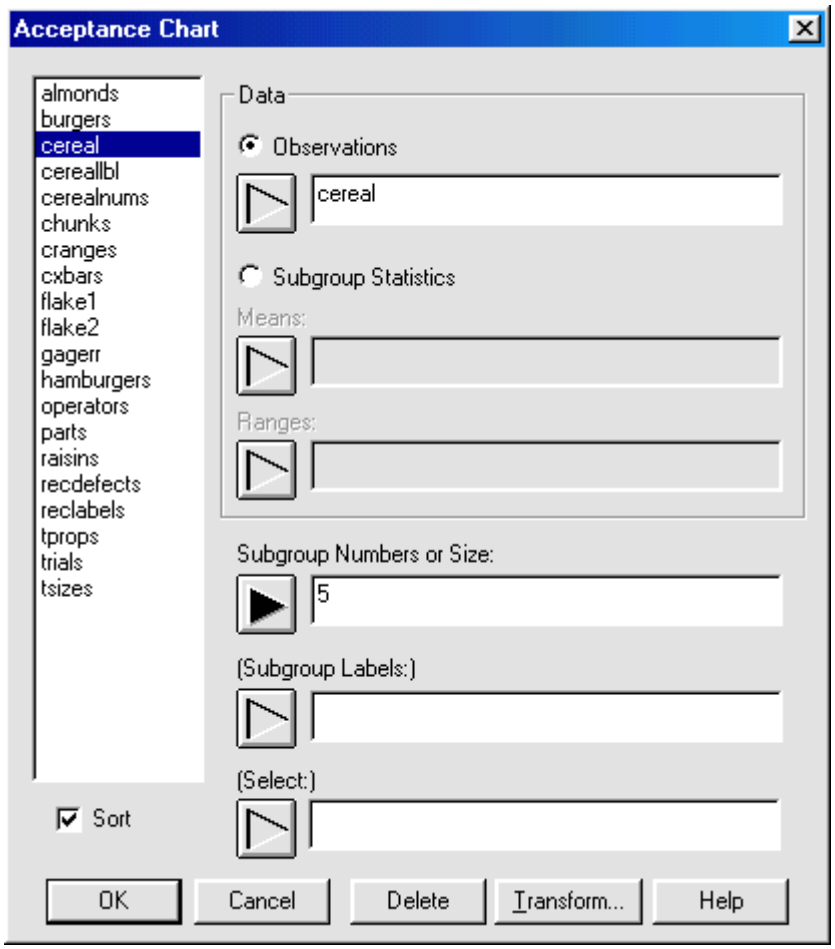


Figure 7-47. Acceptance Chart Analysis Dialog Box

2. Complete the dialog box and click OK to display the Specification Limits dialog box shown in Figure 7-48.

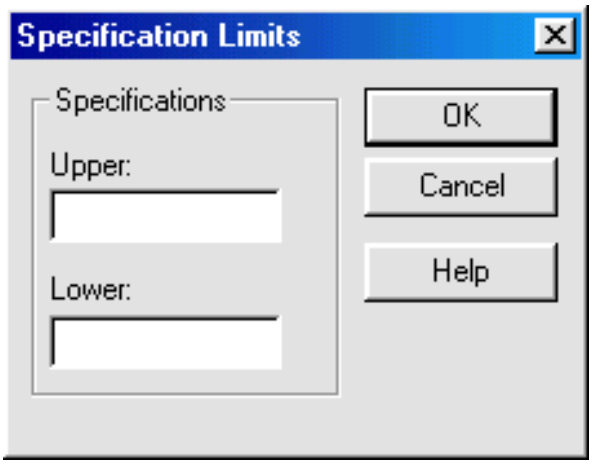


Figure 7-48. Specification Limits Dialog Box

3. Enter values for the Upper and Lower specifications in the text boxes, then click OK to display the Analysis Summary and the Acceptance Chart in the Analysis window.

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 7-49). The summary shows the location of the limits on standard X-bar and S charts. The charts are constructed using the assumption that the data come from a normal distribution with values for the mean and standard deviation estimated from the data.

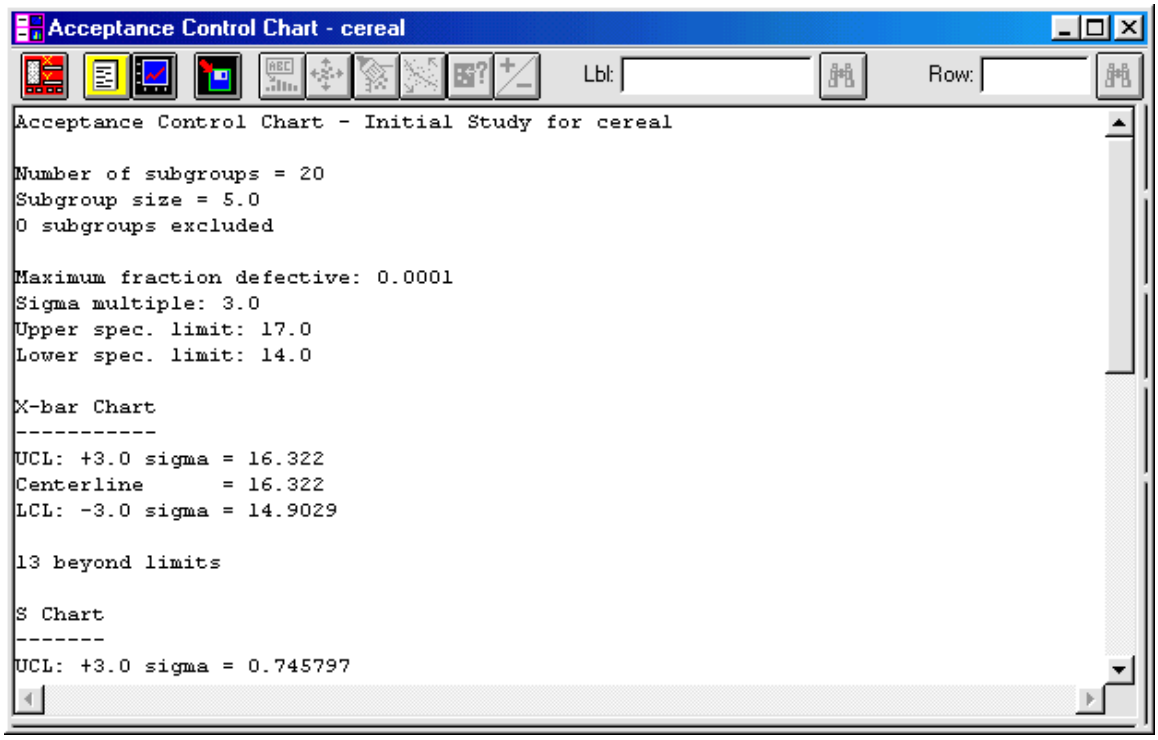


Figure 7-49. Analysis Summary

For both the X-bar Chart and the S Chart, the report displays the values for the upper and lower control limits, the centerline, and the number of subgroups beyond the limits. It shows the number of subgroups, the subgroup size, and the number of subgroups excluded from the study. Also shown are the values used for the maximum fraction defective, and sigma multiple (or unacceptable fraction defective and beta risk) and the upper and lower specification limits. Estimates are also displayed for the process mean, process sigma, and mean sigma.

Use the *Acceptance Chart Options* dialog box to indicate if the study will be an initial or a control to standard; to indicate if sigma multiple or beta risk will be used when calculating the X-bar control limits; to enter values for the Fraction Nonconforming and Sigma Multiple for the X-bar Control Limits (or beta risk); to enter values for the Upper and Lower Sigma for the Range Control Limits; and to change values for the Upper and Lower Specification Limits (see Figure 7-50).

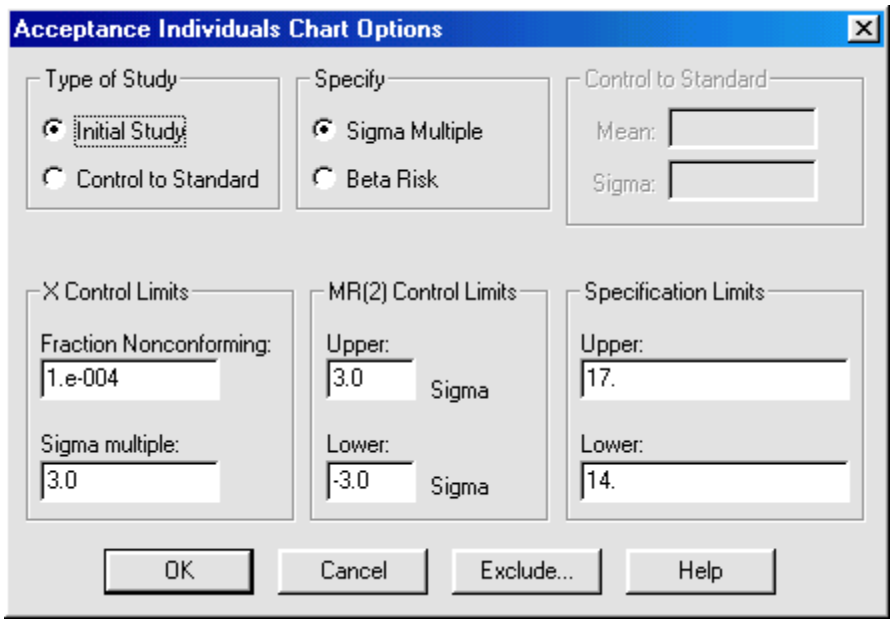


Figure 7-50. Acceptance Chart Options Dialog Box

For a Control-to-Standard Study, you can enter values for the Mean and Sigma.

Use the Exclude... command on the dialog box to choose the subgroups you want to exclude from the analysis. When you click the button, the Exclude/Include Options dialog box displays.

Acceptance Chart Report

The Acceptance Chart Report option creates a report of the subgroups based on your selection on the Acceptance Chart Report Options dialog box (see Figure 7-51). The report shows the values that are plotted on the control chart, including values for the subgroup size, X-bar, and S. It notes points that are beyond the control limits with an asterisk, and points that are excluded with an X.

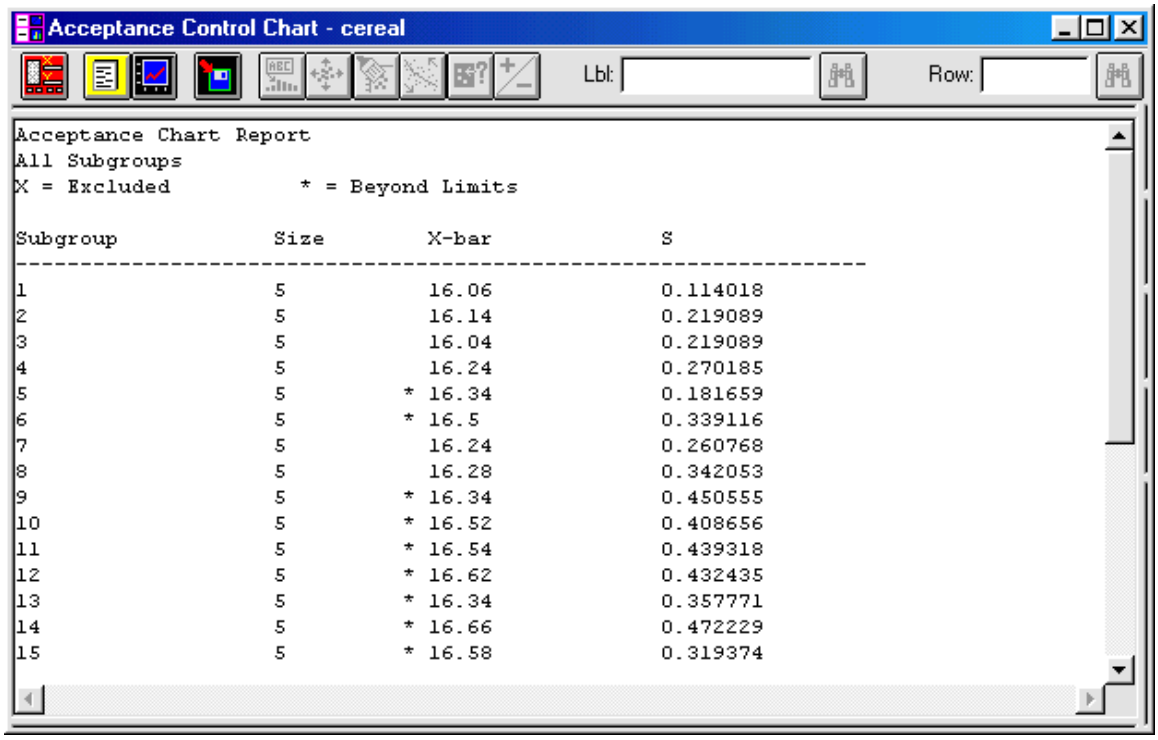


Figure 7-51. Acceptance Chart Report

Use the *Acceptance Chart Report Options* dialog box to choose the report you want to create (see Figure 7-52). You can create a report that displays all the subgroups; subgroups beyond the control limits, X-bars beyond the limits, S beyond the limits, or subgroups that were excluded.

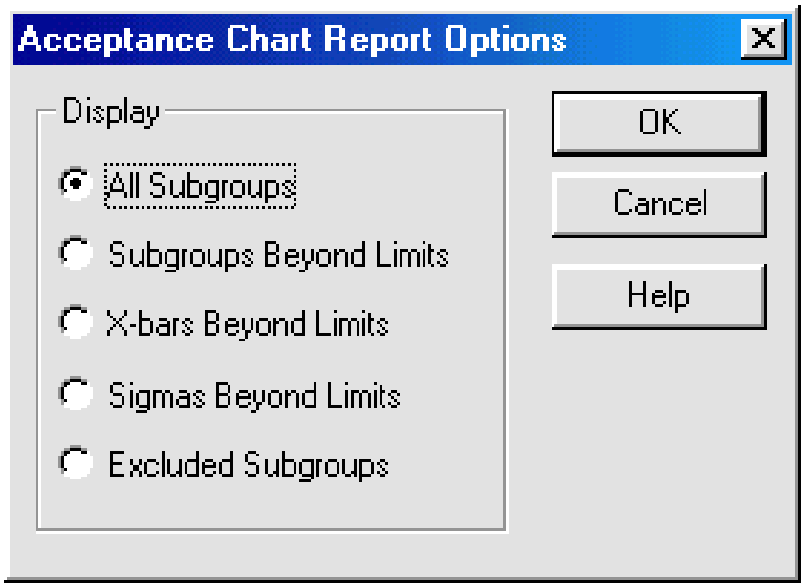


Figure 7-52. Acceptance Chart Report Options Dialog Box

Capability Indices

The Capability Indices option calculates several process capability indices to compare the data with the specifications (see Figure 7-53). The StatAdvisor explains the indices you choose and provides a description of how the indices are calculated. The capability indices C_{pm} and K will not be calculated until you enter a value for the Nominal on the Process Capability Indices Options dialog box.

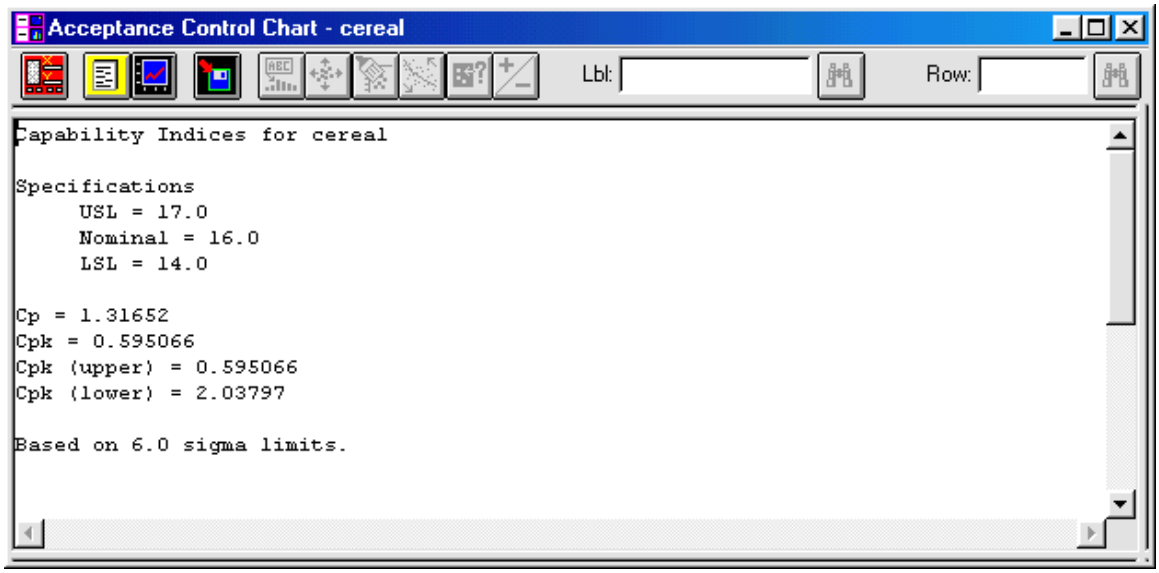


Figure 7-53. Capability Indices

Use the *Process Capability Indices Options* dialog box to choose the indices you want to include, and to enter a value for the nominal.

Graphical Options

Acceptance Chart

The Acceptance Chart option creates an Acceptance Chart for each of the subgroup averages and shows the points that are beyond the control limits (see Figure 7-54).

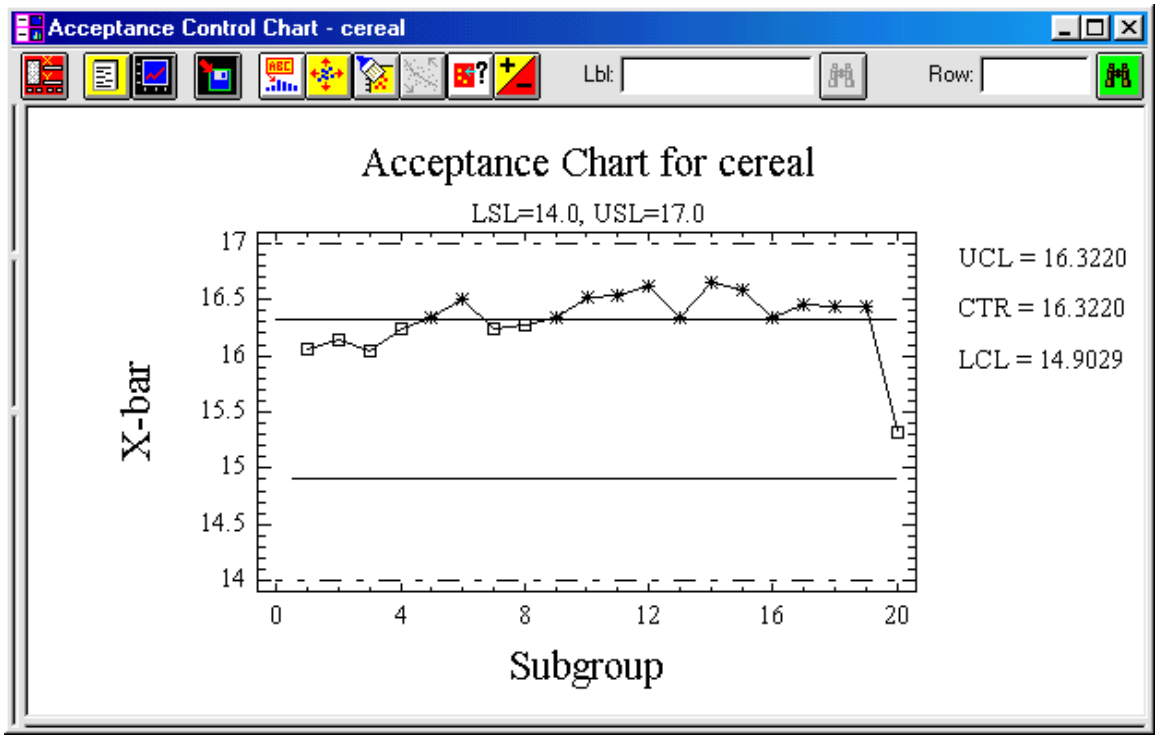


Figure 7-54. Acceptance Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; to indicate if you want the simple moving average of the subgroup statistics superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the subgroup statistics superimposed on the chart, and if so, to enter a value for lambda; and to enter the number of decimal places that will be used to display the limits.

S Chart

The S Chart option creates a plot of the standard deviations for each of the subgroups and shows the points that are beyond the control limits (see Figure 7-55).

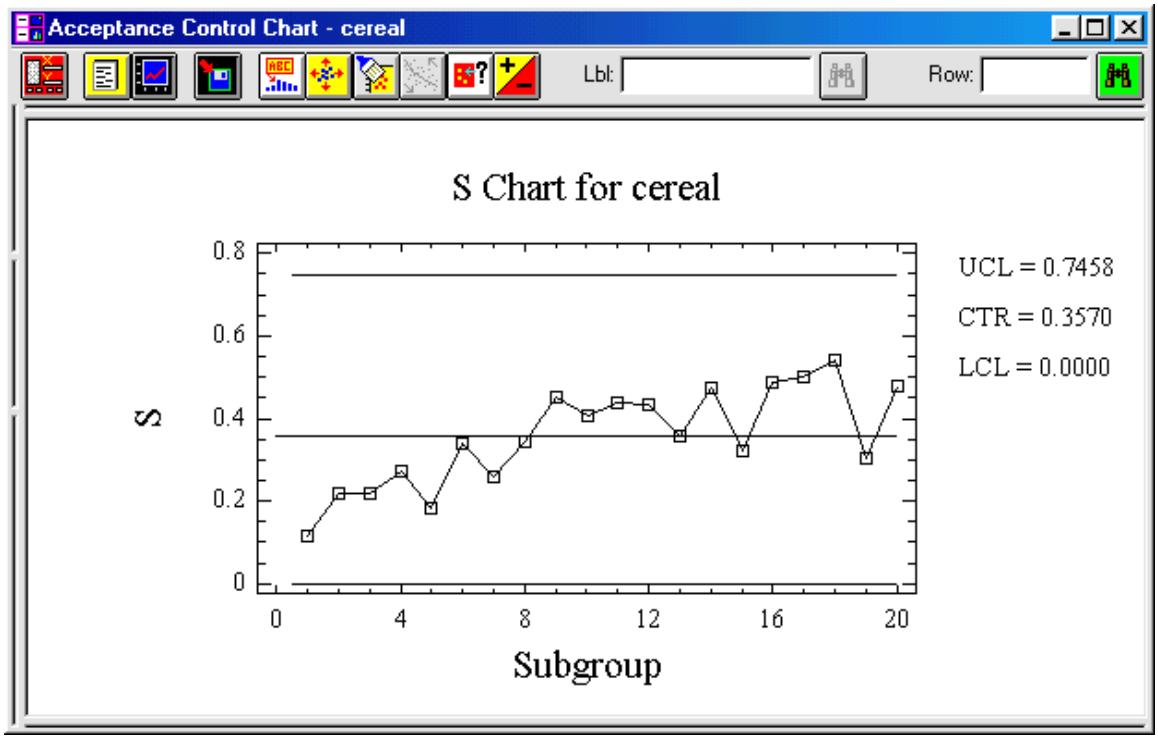


Figure 7-55. S Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer and/or inner warning limits, and if so, to enter the number of sigmas from the centerline the inner and/or outer warning limits will be plotted; to indicate if you want the simple moving average of the subgroup statistics superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the subgroup statistics superimposed on the chart, and if so, to enter a value for lambda; and to enter the number of decimal places that will be displayed for in the limits.

Tolerance Chart

The Tolerance Chart option creates a plot of the individual values, organized by subgroup (see Figure 7-56). The horizontal line indicates the grand mean of the observations. The vertical lines indicate the subgroup ranges. Because you use this option to examine individual observations, the chart is available only when you select Observations from the Data options on the Analysis dialog box.

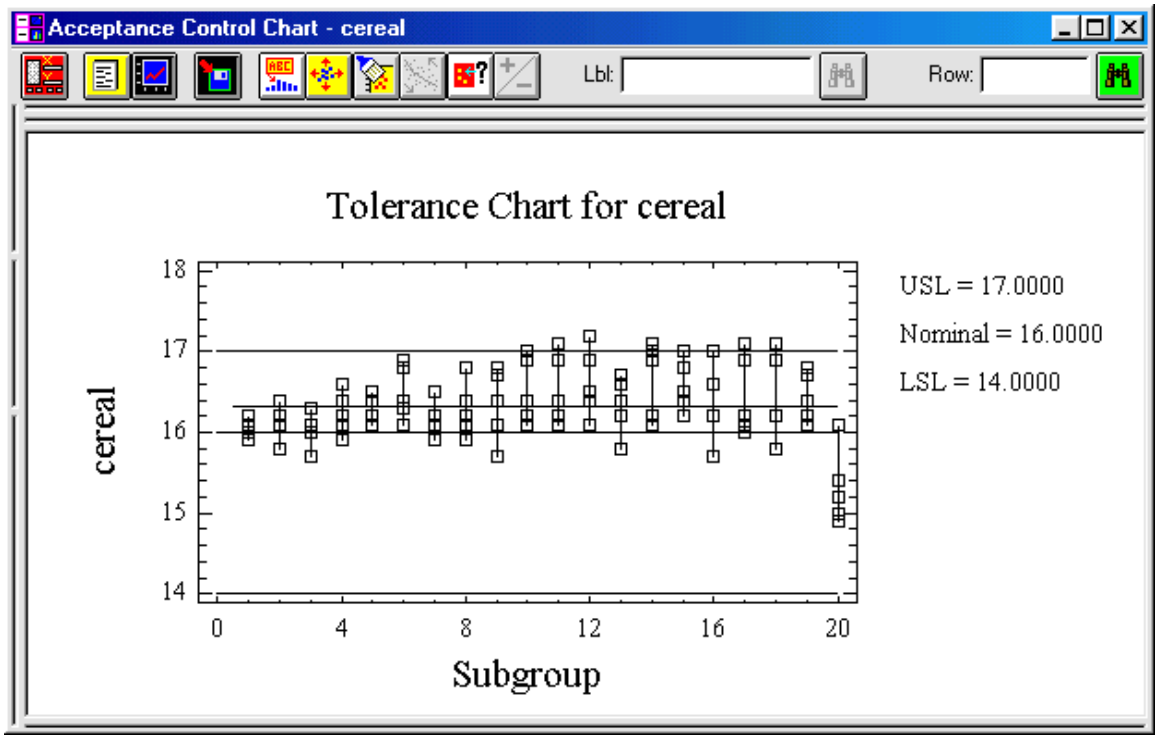


Figure 7-56. Tolerance Chart

Use the *Tolerance Chart Options* dialog box to enter a value for the Nominal, to enter the number of decimal places that should be used to display the limits, and to indicate if points or the nominal specification line will display on the plot.

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point that is plotted on the control chart will remain inside the control limits as a function of the true process mean (see Figure 7-57). It is useful for judging the effectiveness of a control chart in detecting when a process drifts away from the target. The X-axis shows the shift in the average; the Y-axis the probability of not detecting the shift.

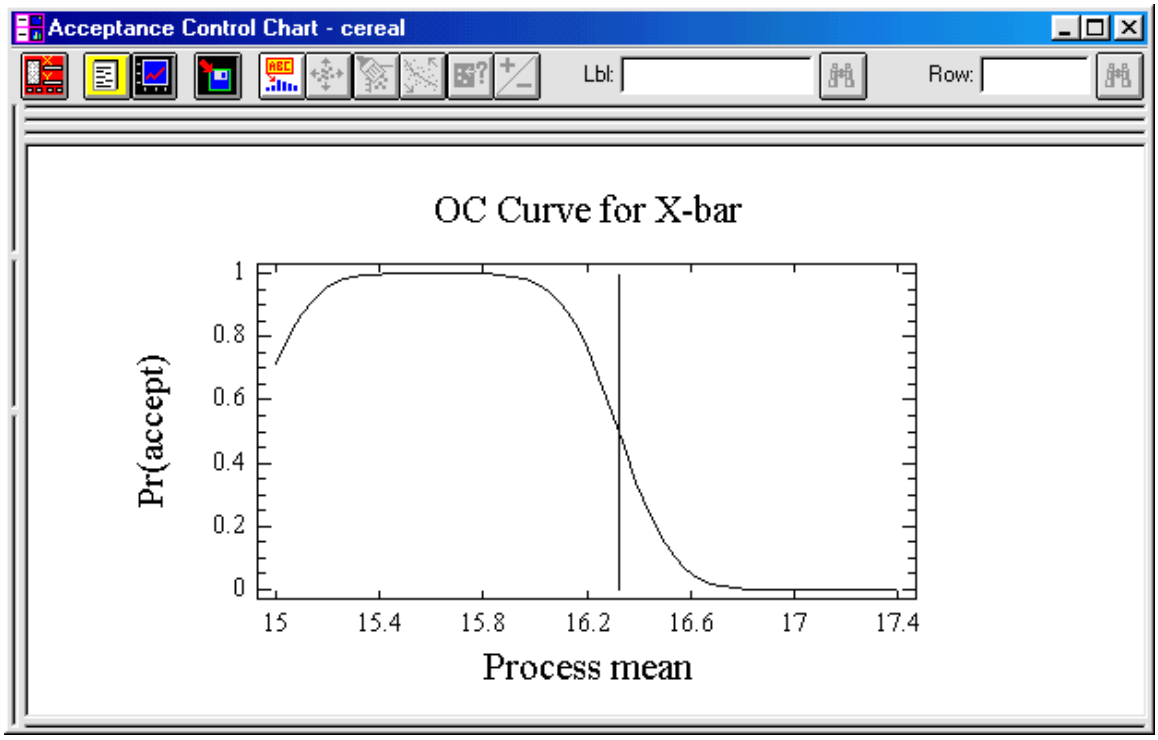


Figure 7-57. OC Curve

ARL Curve

The ARL Curve option creates a plot that shows the average run length (ARL) as a function of the process mean (see Figure 7-58). For example, if the process is actually running at centerline, the chart should generate an out-of-control signal on an approximate average based on the number of samples. If the process moves away from the centerline, the average run length will change. The plot is helpful in choosing an adequate sampling plan to monitor the process.

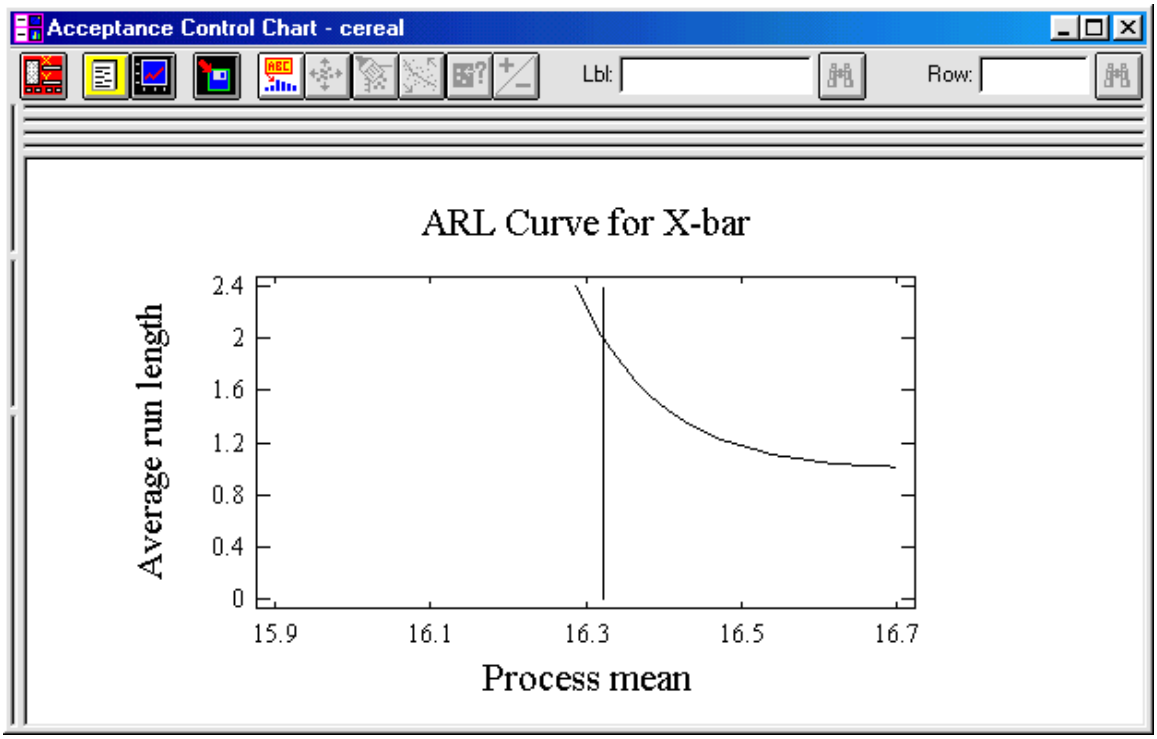


Figure 7-58. ARL Chart

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are six selections: Means, Sigmas, Sizes, Labels, Process Mean, and Process Sigma.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the Acceptance Individuals Control Chart Analysis

Acceptance charts are one of two methods used for relaxing the level of surveillance provided by a standard control chart (Montgomery, 1997). The purpose of the analysis is to monitor processes that tend to operate well within process specifications (with high C_p). Rather than place the control limits at +/- 3 sigma from the centerline, STATGRAPHICS *Plus* places them relative to the specification

limits. This allows the process to drift around the centerline, while still ensuring that little if any product is out of specification.

The basis of the Acceptance Chart is controlling both the risk of rejecting a satisfactory process (α-risk), and the risk of accepting an unsatisfactory process (β-risk).

The functionality in the Acceptance Individuals Chart Analysis is identical to that in the Acceptance Chart Analysis, except that you use individual observations instead of subgroups.

To Access the Acceptance Individuals Control Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... SPECIAL PURPOSE CONTROL CHARTS... ACCEPTANCE INDIVIDUALS CONTROL CHART... to display the Analysis dialog box shown in Figure 7-59.

2. Complete the dialog box and click OK to display the Specification Limits dialog box shown in Figures 7-60.

3. Enter values for the Upper and Lower specifications in the text boxes, then click OK to display the Analysis Summary and the Acceptance Chart in the Analysis window.

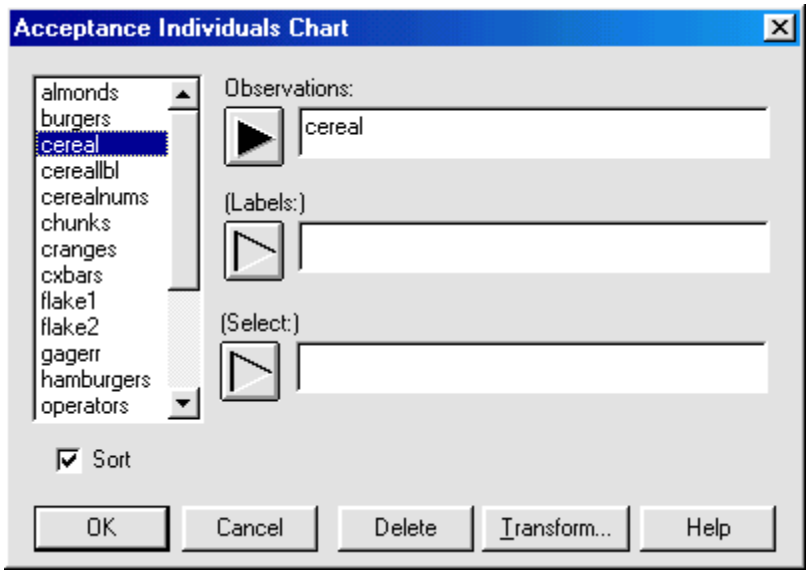
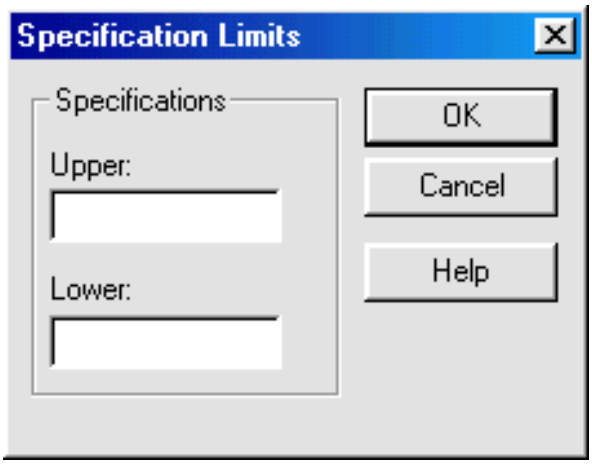


Figure 7-59. Acceptance Individuals Chart Analysis Dialog Box



Figures 7-60. Specification Limits Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis for either an initial or a control-to-standard study that helps determine if the data come from a process that is in statistical control (see Figure 7-61). The summary shows the location of the limits on standard X and MR(2) charts. The charts are constructed using the assumption that the data come from a normal distribution with values for the mean and standard deviation estimated from the data.

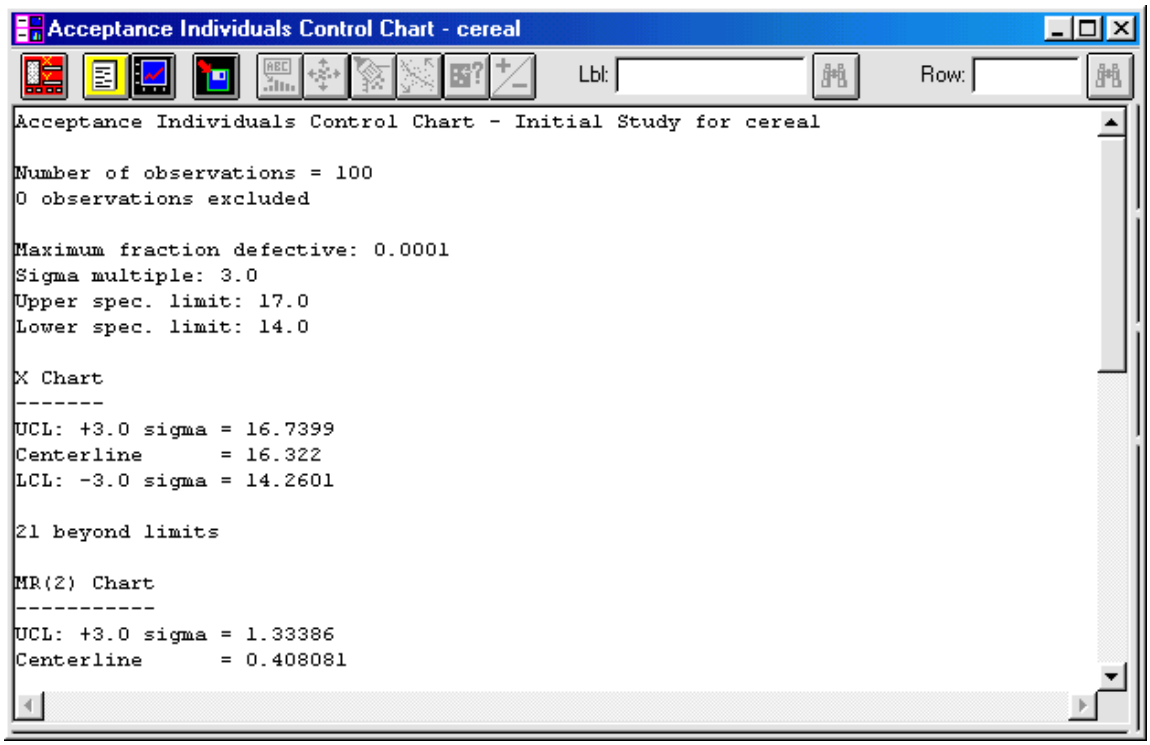


Figure 7-61. Analysis Summary

For both the X Chart and the MR(2) Chart, the report displays the values for the upper and lower control limits, the centerline, and the number of observations beyond the limits. It shows the number of observations, and the number of observations excluded from the study. Also shown are the values used for the maximum fraction defective and sigma multiple (or unacceptable fraction defective and beta risk) and the upper and lower specification limits. Estimates are also displayed for the process mean, process sigma, and mean MR(2).

Use the *Acceptance Individuals Chart Options* dialog box to indicate if the study will be an initial or a control to standard; to indicate if sigma multiple or beta risk will be used when calculating the X Chart control limits; to enter values for the Fraction Nonconforming and Sigma Multiple (or Beta Risk) for the X Control Limits; to enter values for the Upper and Lower Sigma for the MR(2) Control Limits; and to change the values for the Upper and Lower Specification Limits (see Figure 7-62).

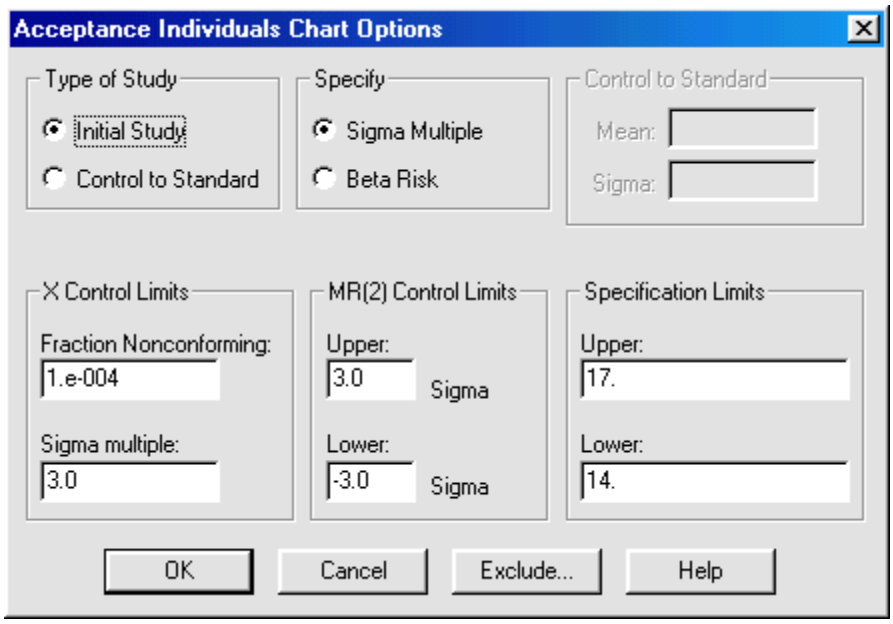


Figure 7-62. Acceptance Individuals Chart Options Dialog Box

For a Control-to-Standard study, you can enter values for the Mean and Sigma. *See Online Help for a complete description of each of these text boxes.*

Use the Exclude... command on the dialog box to choose the observations you want to exclude from the analysis. When you click the button, the Exclude/Include Options dialog box displays.

Acceptance Individuals Chart Report

The Acceptance Individuals Chart Report option creates a report of the values that were plotted on the control chart, including values for X and MR(2), as well as a list of the observation number (see Figure 7-63). It notes points that are beyond the control limits with an asterisk, and points that are excluded with an X.

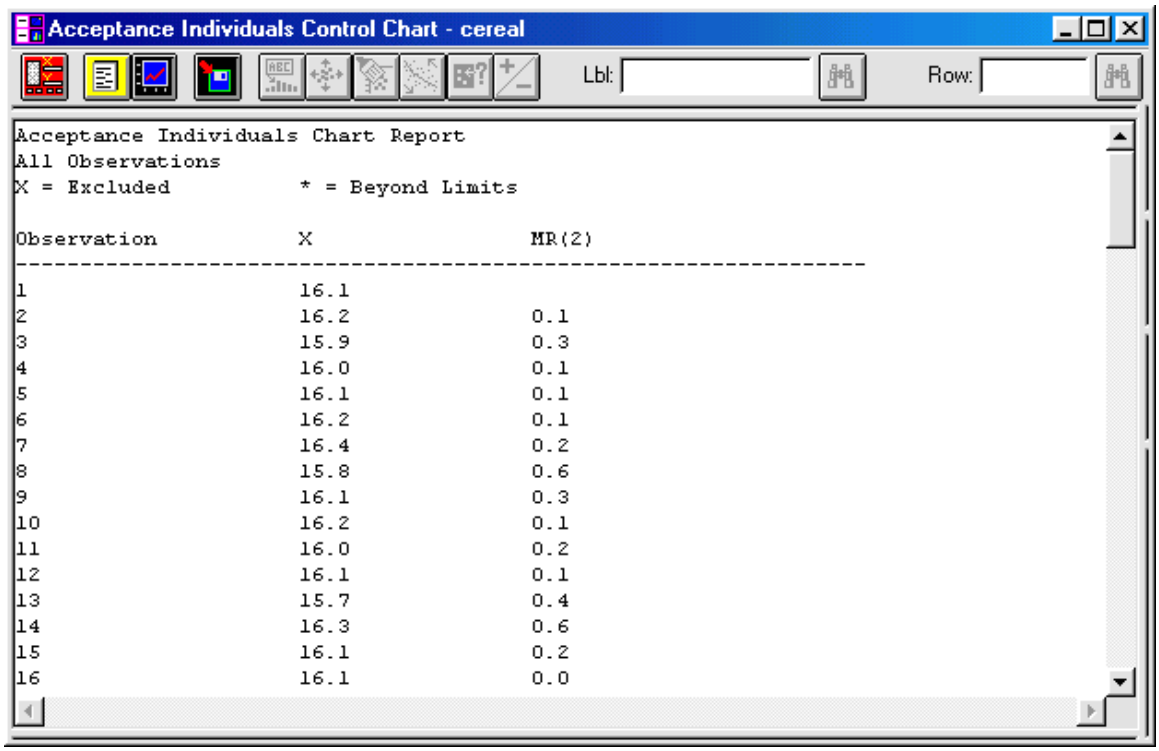


Figure 7-63. Acceptance Individuals Chart Report

Use the *Acceptance Individuals Chart Report Options* dialog box to choose the report you want to create (see Figure 7-64). You can create a report that displays all the observations; observations beyond the control limits, X′s beyond the limits, MR(2)′s beyond the limits, or observations that were excluded.

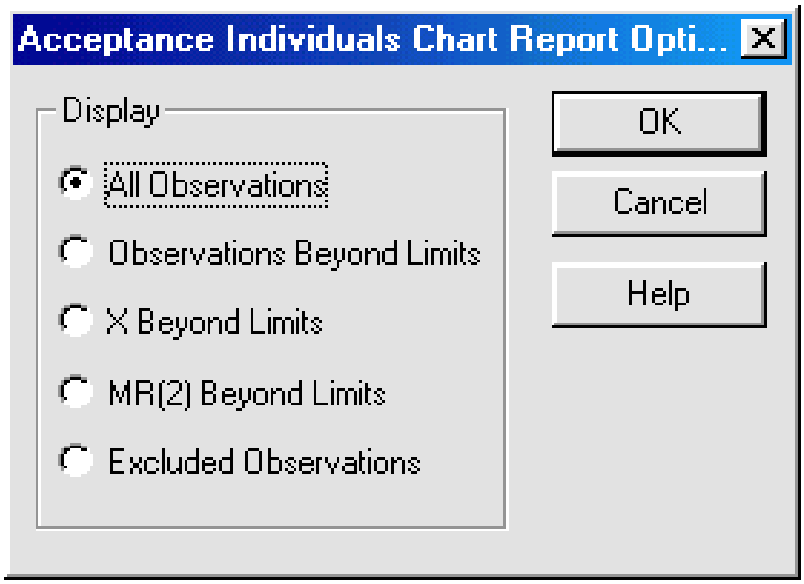


Figure 7-64. Acceptance Individuals Chart Report Options Dialog Box

Capability Indices

The Capability Indices option calculates several process capability indices to compare the data with the specifications (see Figure 7-65). The StatAdvisor explains the indices you choose and provides a description of how the indices are calculated. The capability indices C_{pm} and K will not be calculated until you enter a value for the Nominal on the Process Capability Indices Options dialog box.

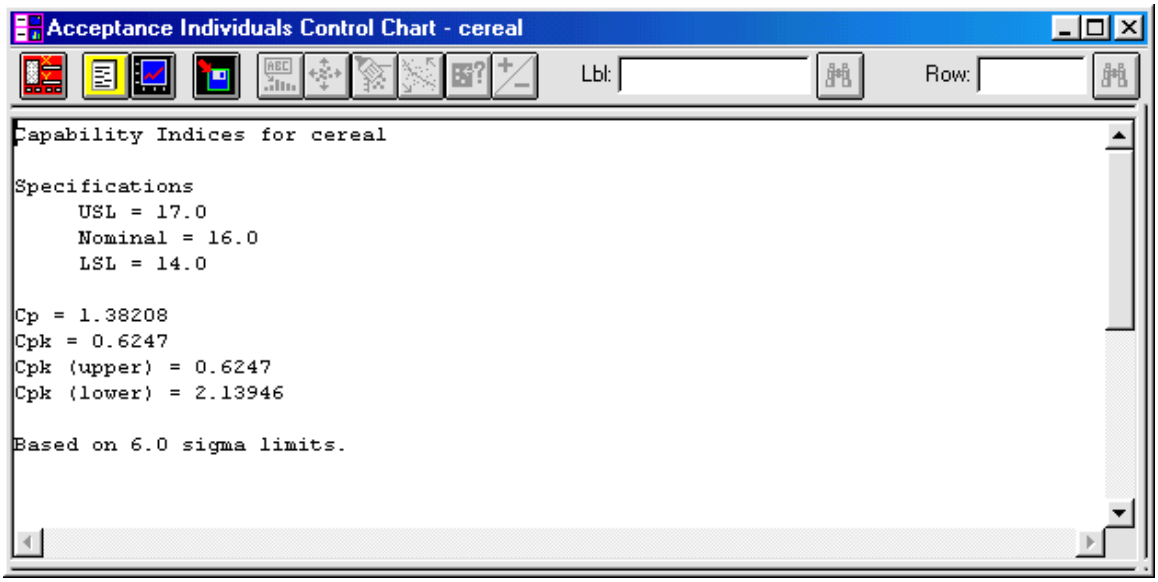


Figure 7-65. Capability Indices

Use the *Process Capability Indices Options* dialog box to choose the indices you want to include, and to enter a value for the nominal.

Graphical Options

Acceptance Chart

The Acceptance Chart option creates a plot of the observations (see Figure 7-66). It notes the points that are beyond the control limits.

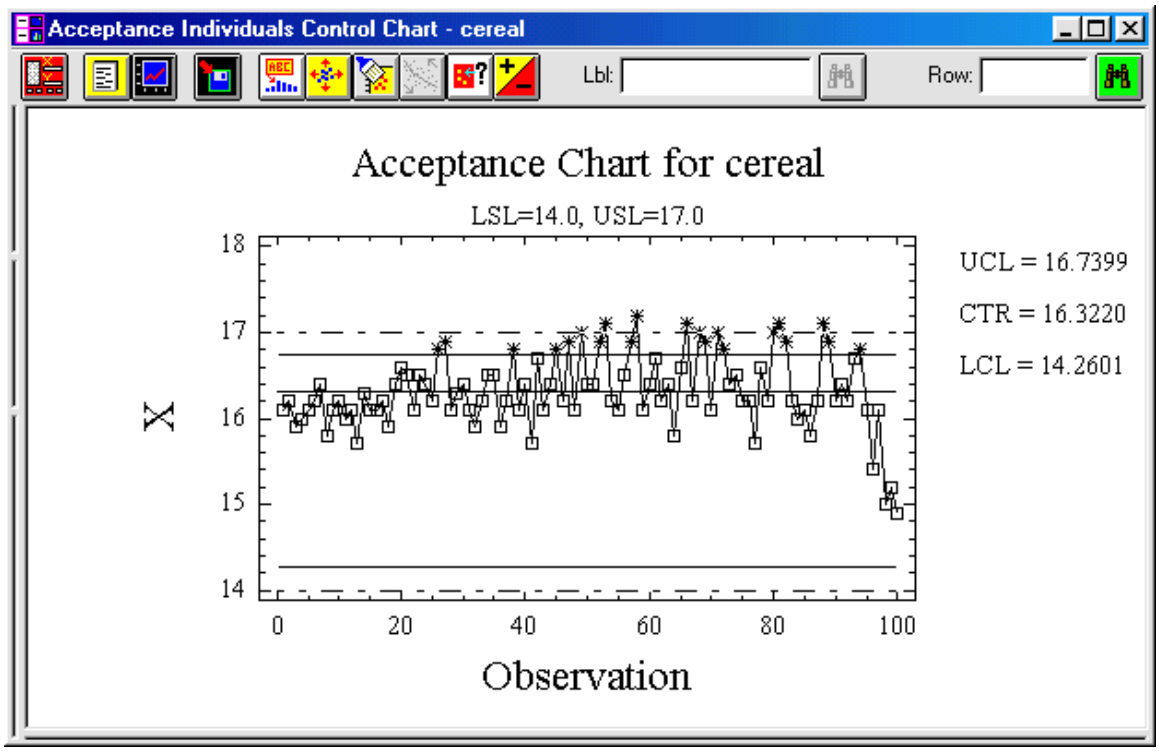


Figure 7-66. Acceptance Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer/inner warning limits, and if so, to enter the number of sigmas from the centerline the inner/outer warning limits will be plotted; to indicate if you want the simple moving average of the observations superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the observations superimposed on the chart, and if so, to enter a value for lambda; and to enter the number of decimal places that will be used to display the limits.

MR(2) Chart

The MR(2) Chart option creates a plot of the moving ranges for each of the measurements and shows the points that are beyond the control limits (see Figure 7-67).

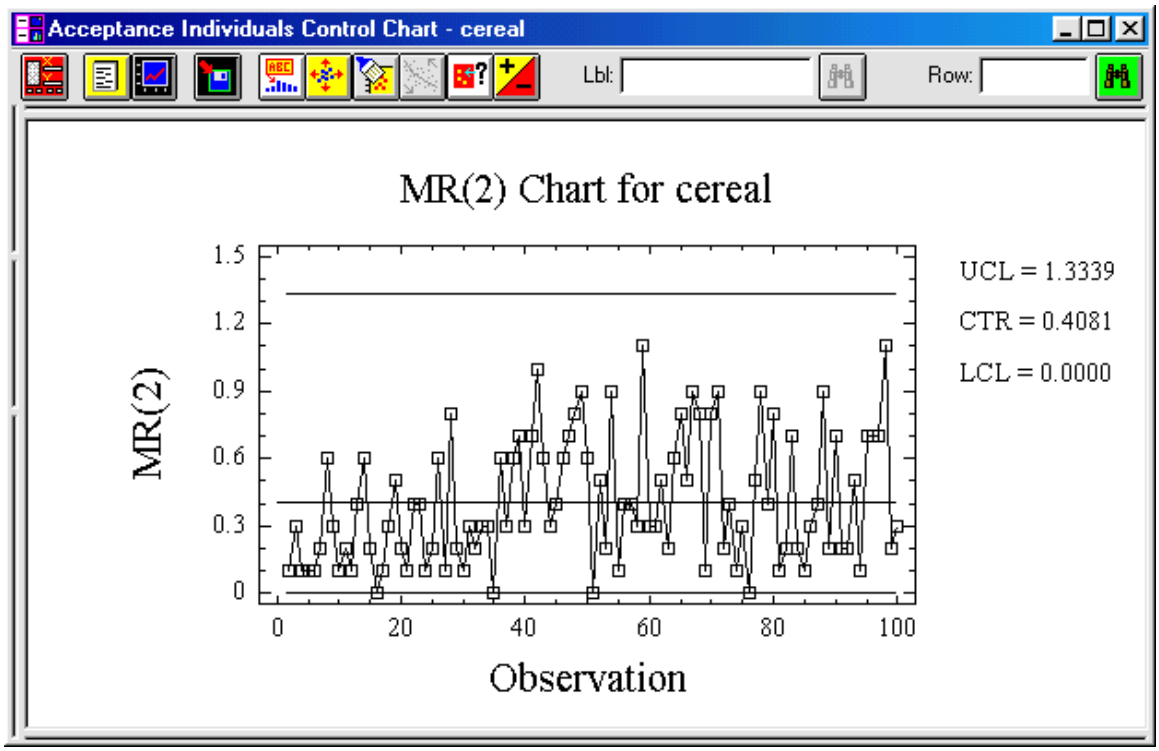


Figure 7-67. MR(2) Chart

Use the *Control Chart Options* dialog box to indicate if you want to plot outer/inner warning limits, and if so, to enter the number of sigmas from the centerline the inner/outer warning limits will be plotted; to indicate if you want the simple moving average of the moving ranges superimposed on the chart, and if so, to enter the order; to indicate if you want an exponentially weighted moving average of the moving ranges superimposed on the chart, and if so, to enter a value for lambda; and to enter the number of decimal places that will be used for displaying the limits.

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability that the next point plotted on the control chart will remain inside the control limits as a function of the true process mean (see Figure 7-68). In other words, it plots the probability that there will not be a signal from the chart, even though the process is not at the assumed center. The results are useful when you need to determine the effectiveness of the control chart in detecting drifts in the process away from the target. The X-axis shows the shift in the average; the Y-axis shows the probability of not detecting the shift.

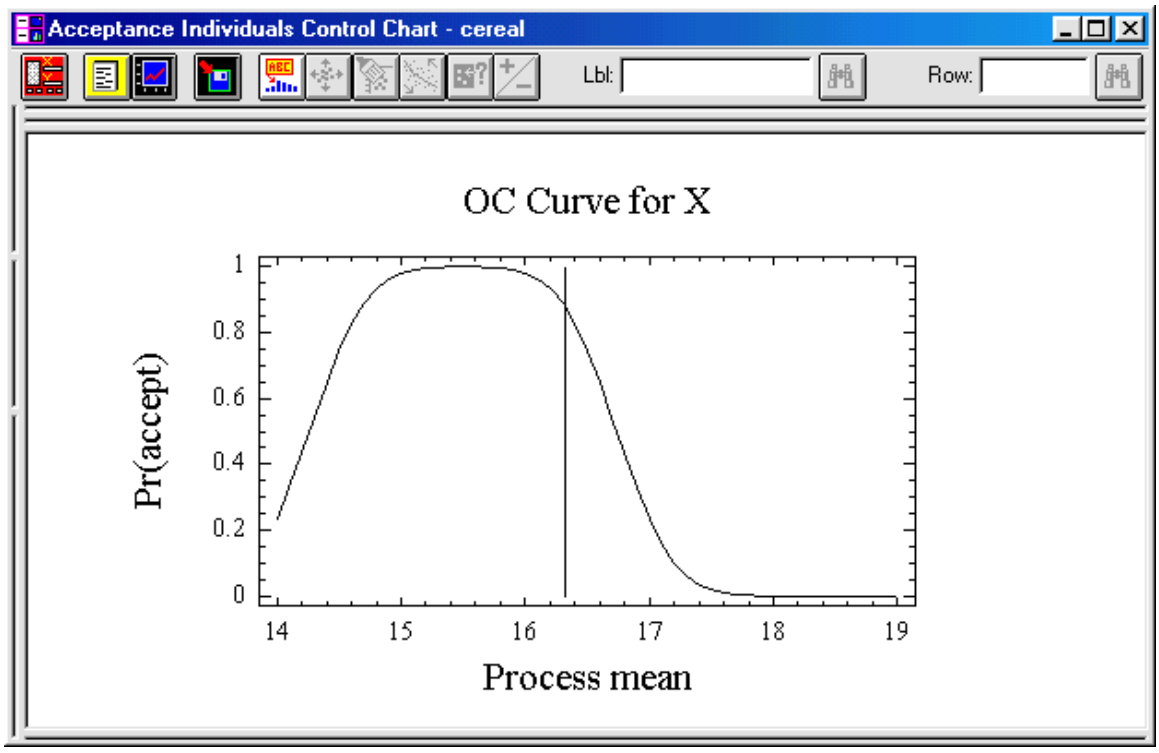


Figure 7-68. OC Curve

ARL Curve

The ARL (Average Run Length) Curve option creates a plot that shows the ARL for the Acceptance Chart as a function of the process mean (see Figure 7-69). For example, if the process is actually running at the centerline, the chart will create an out-of-control signal on average for the number of samples. If the process moves away from the centerline, the ARL will change accordingly. The plot is helpful when you need to select an adequate sampling plan to monitor the process.

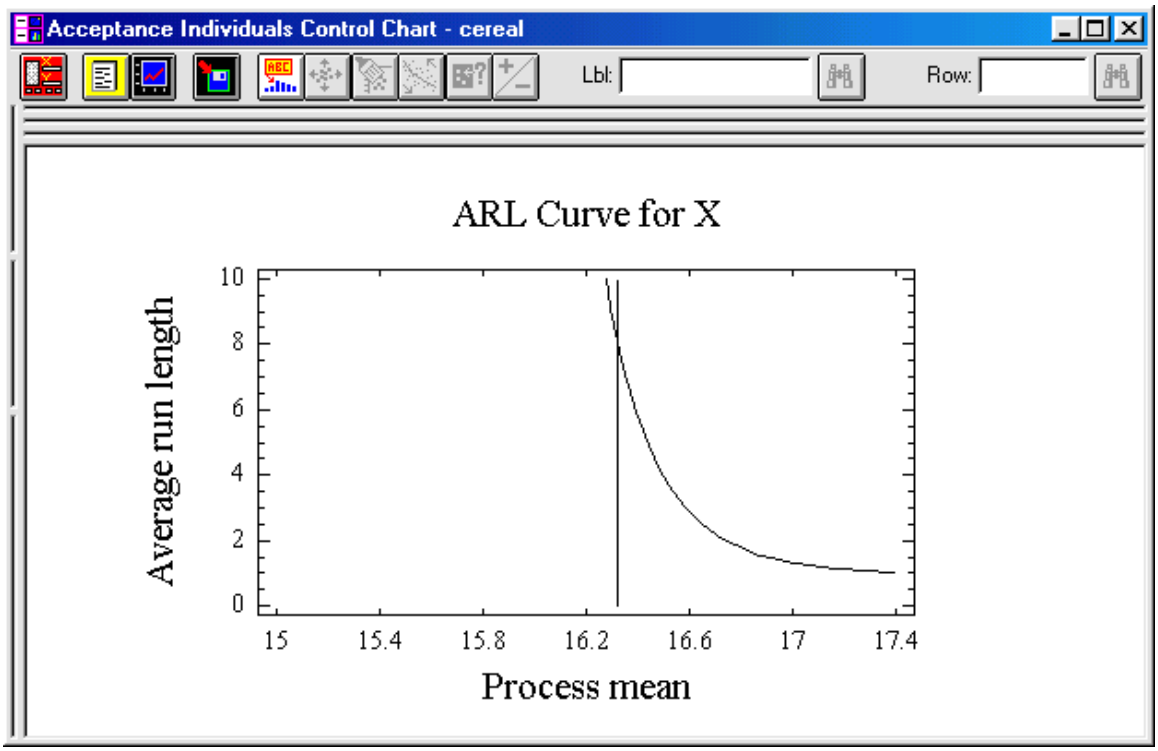


Figure 7-69. ARL Curve

Saving the Results

The Save Results Options dialog box allows you to choose the results you want to save. There are six selections: Observations, Moving Ranges, Labels, Process Mean, Process Sigma, and Included Observations.

You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

References

AT&T. 1956. *Statistical Quality Control Handbook, Select Code 700-444.* Indianapolis: AT&T Technologies.

Duncan, A. J. 1986. *Quality Control and Industrial Statistics*, fifth edition. Homewood, Illinois: Richard D. Irwin, Inc.

Grant, E. L. and Leavenworth, R. S. 1980. *Statistical Quality Control*, fifth edition. New York: McGraw-Hill Book Company.

Makridakis, S., Wheelwright, S. C., and McGee, V. E. 1983. *Forecasting: Methods and Applications*, second edition. New York: John Wiley & Sons.

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Chapter 8

USING GAGE R&R

Background Information

In modern industry, being able to interchange uniform parts is vital for cost-effective manufacturing. If a machine part fails or wears out, a replacement must be available and it must fit. When failures occur, data on the replacement parts and the manufacturing processes are analyzed to determine if they conform to product specifications, then the data are fed back to the manufacturing process to prevent further production problems.

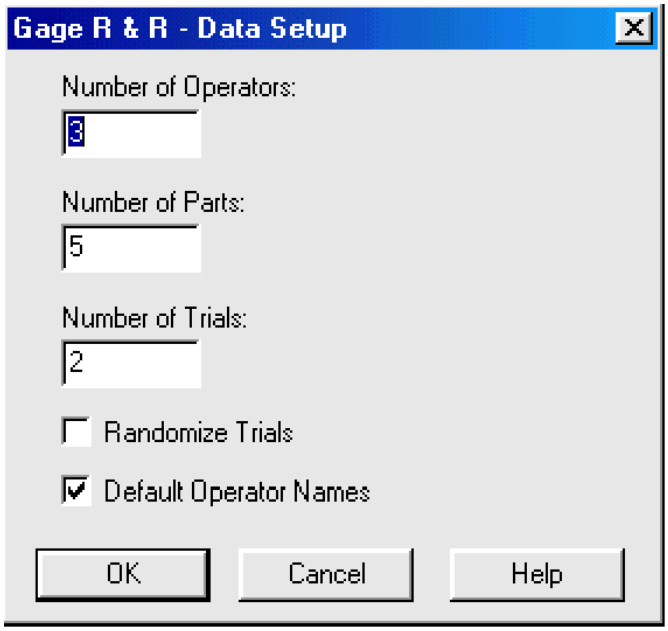
Two types of variability can occur in the manufacturing processes: repeatability and reproducibility (R&R). Repeatability or equipment variation, measures the precision of the gage or the measurement tool, and is the variation obtained when one person, using the same measuring instrument, measures the same dimension two or more times. Reproducibility or inspector variation, is the variation in measurement averages obtained when several operators, using one gage, measure the same characteristic on the same part.

The Gage R&R Analysis in STATGRAPHICS Plus allows you to set up and perform an analysis of the repeatability and reproducibility components of gage variability. Three analysis methods are provided: Average and Range, ANOVA, and Range. Before you actually perform the analysis, you begin by using Gage R&R Data Setup to build a file that can be used with any of the three methods.

Gage R&R

In the *Gage R&R Data Setup* feature, you create variables that contain different combinations of operators, parts, and trials. You can create new variables using the DataEditor, or use existing variables. To save the setup in a DataSheet, click the Save Results button to save all the results in an empty DataSheet.

To Access the Gage R&R Data Setup, Choose SPECIAL... QUALITY CONTROL... GAGE R&R... DATA SETUP... from the Menu bar to display the Gage R&R - Data Setup dialog box shown in Figure 8-1.



s

Complete the dialog box and click OK to display the Analysis Summary. Click the Save Results button on the Analysis toolbar (the fourth button from the left), to display the Save Results Options dialog box. Choose the option that indicates the type of results you want to save, then click OK to save the data for analyzing with one of the three methods.

Tabular Options

Analysis Summary

The *Analysis Summary* option creates a summary that includes the number of operators, parts, and trials; indicates if runs were generated in a random or nonrandom order; and indicates if default names or names you supplied were used in the setup (see Figure 8-2). The summary also shows the setup for the operators, parts, and trials.

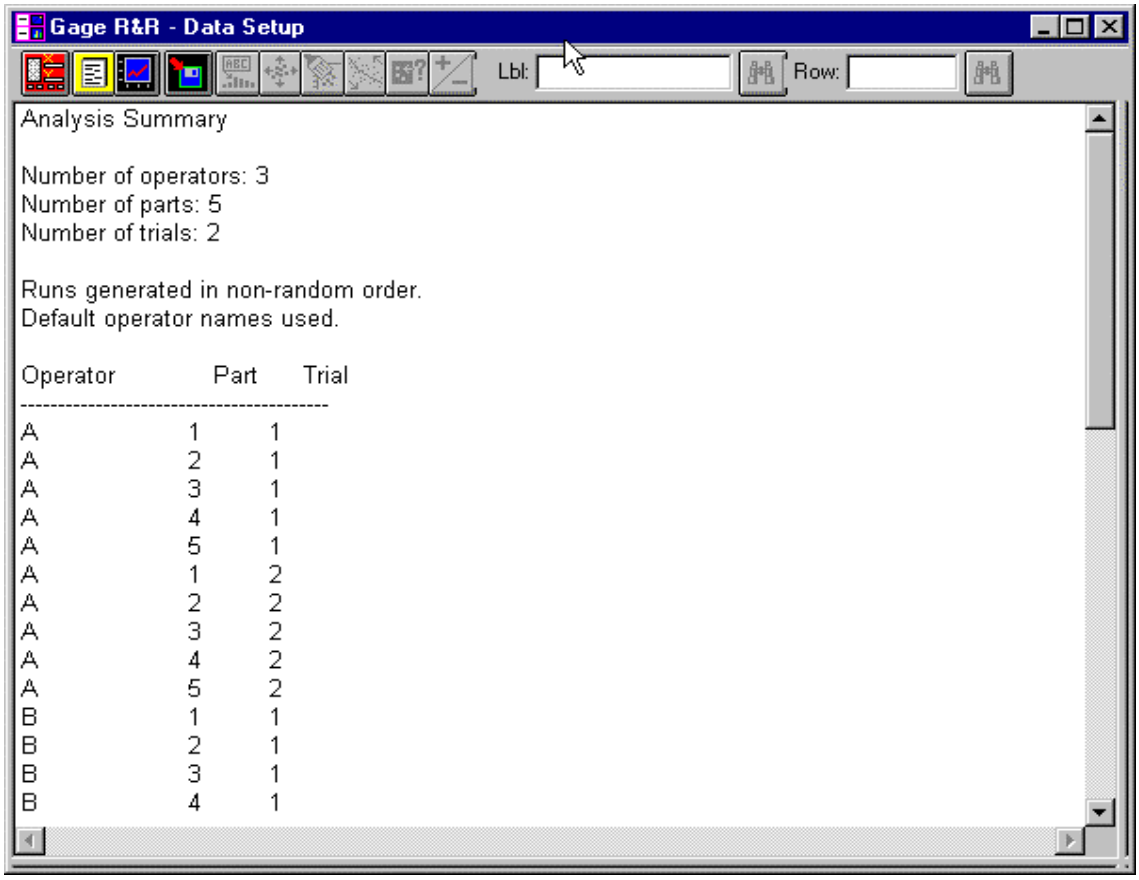


Figure 8-2. Analysis Summary

Saving the Results

The Save Results Options dialog box allows you to select the results you want to save: Operators, Parts, Trials, or Measurements. You can also use the Target Variables text boxes to enter the names of the variables in which you want to save the values generated during the analysis. You can enter new names or accept the defaults.

Note: To access the Save Results Options dialog box, click the Save Results Options button on the Analysis toolbar (the fourth button from the left).

Using the Average and Range Method

The *Average and Range Method* (sometimes referred to as the Long Method), is a mathematical method for assessing a measurement system. This method allows the measurement system to "decompose" into two separate components: repeatability and reproducibility. This method is a full gage repeatability and reproducibility analysis involving multiple operators, parts, and replications that estimates both repeatability and reproducibility.

To use this method, you must set up variables that contain operator names, part numbers, trial numbers, and measurements. The design must be balanced; that is, each operator must measure each part the same number of times.

To Access the *Average and Range Method*, choose SPECIAL... QUALITY CONTROL... GAGE R&R... AVERAGE AND RANGE METHOD... from the Menu bar to display the Average and Range Method dialog box shown in Figure 8-3. Complete the dialog box and click OK to display the Analysis Summary and the Operator and Part Plot in the Analysis window.

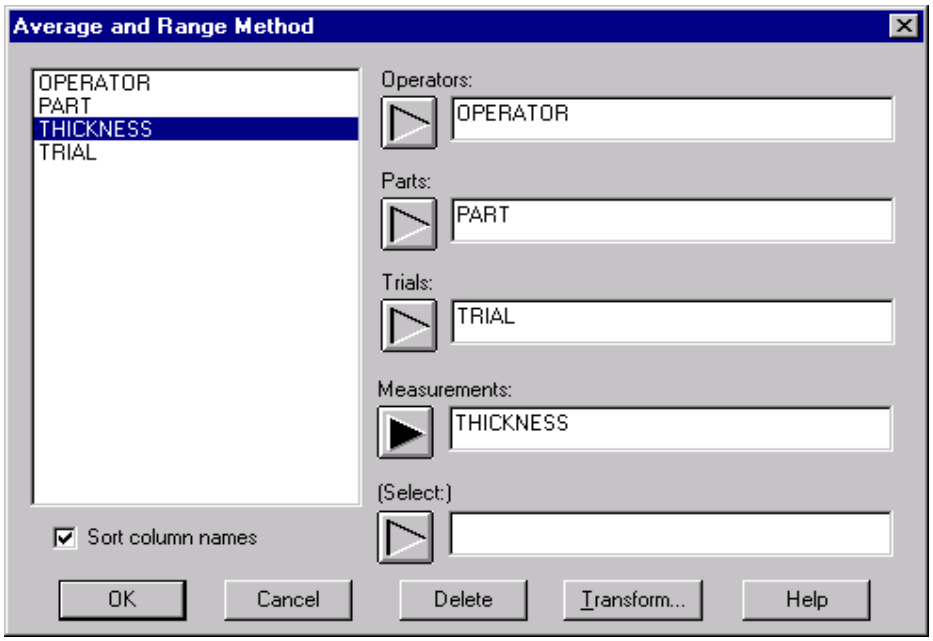


Figure 8-3. Average and Range Method Dialog Box

Tabular Options

Analysis Summary

The *Analysis Summary* pane contains a summary of the analysis that includes the names of the operators, parts, trials, and measurement variables (see Figure 8-4). It summarizes the operators, parts, and trials; and shows the average range and the range of the X-bars.

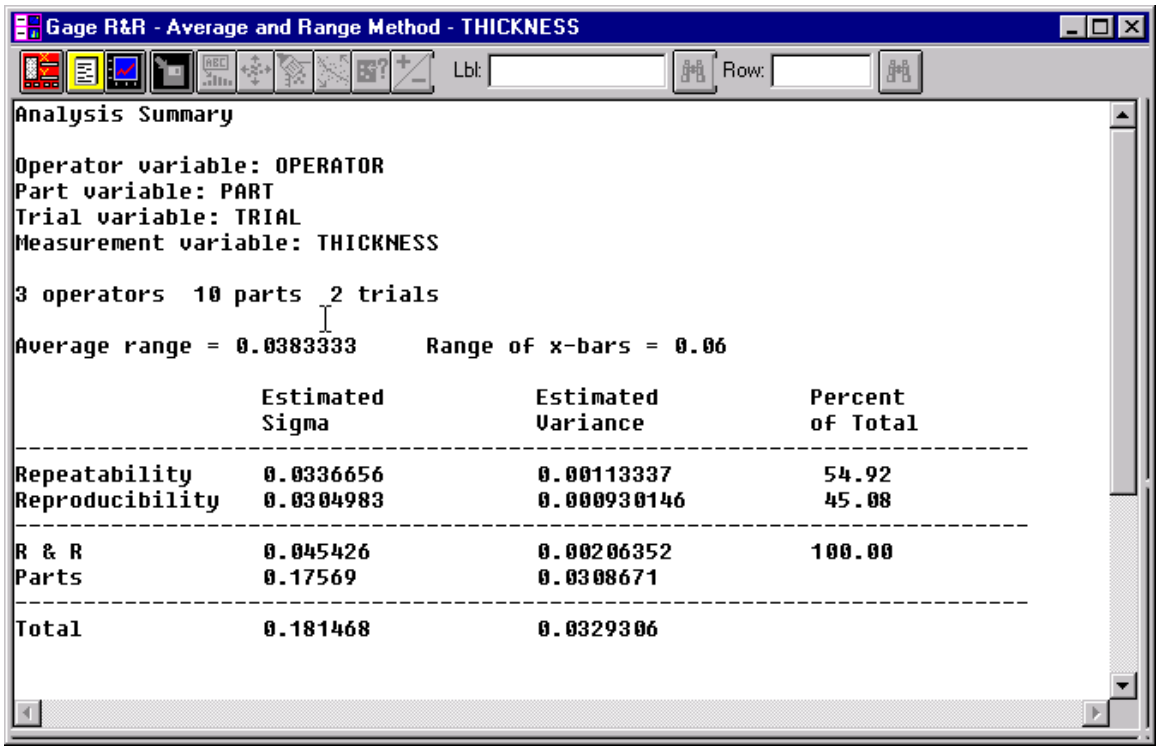


Figure 8-4. Analysis Summary

The table in the summary displays values for the Estimated Sigma, Estimated Variance, and Percent of Total. Estimated Sigma values are the standard deviation for the measures of Repeatability, Reproducibility, a combination of the two (R&R), Parts and Total. Estimated Variance values include the measure of Repeatability, Reproducibility, a combination of the two (R&R), Parts and Total. Percent of Total is the amount of the total estimated variance that can be attributed to repeatability versus reproducibility.

Use the ***Average and Range Method Options*** dialog box to enter values for the tolerance, sigma intervals, process sigma, and confidence level (see Figure ***8-5).***

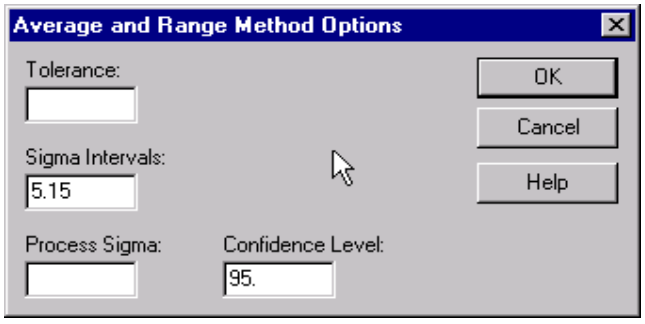


Figure 8-5. Average and Range Method Options Dialog Box.

Gage Report

The Gage Report option displays the measurement unit analysis, study variation table, and confidence intervals (see Figure 8-6). The table shows the intervals equal to a percentage times the standard deviations due to repeatability, reproducibility, combined R&R, and part-to-part variation. The intervals can be expected to contain a given percentage of the errors attributed to each source.

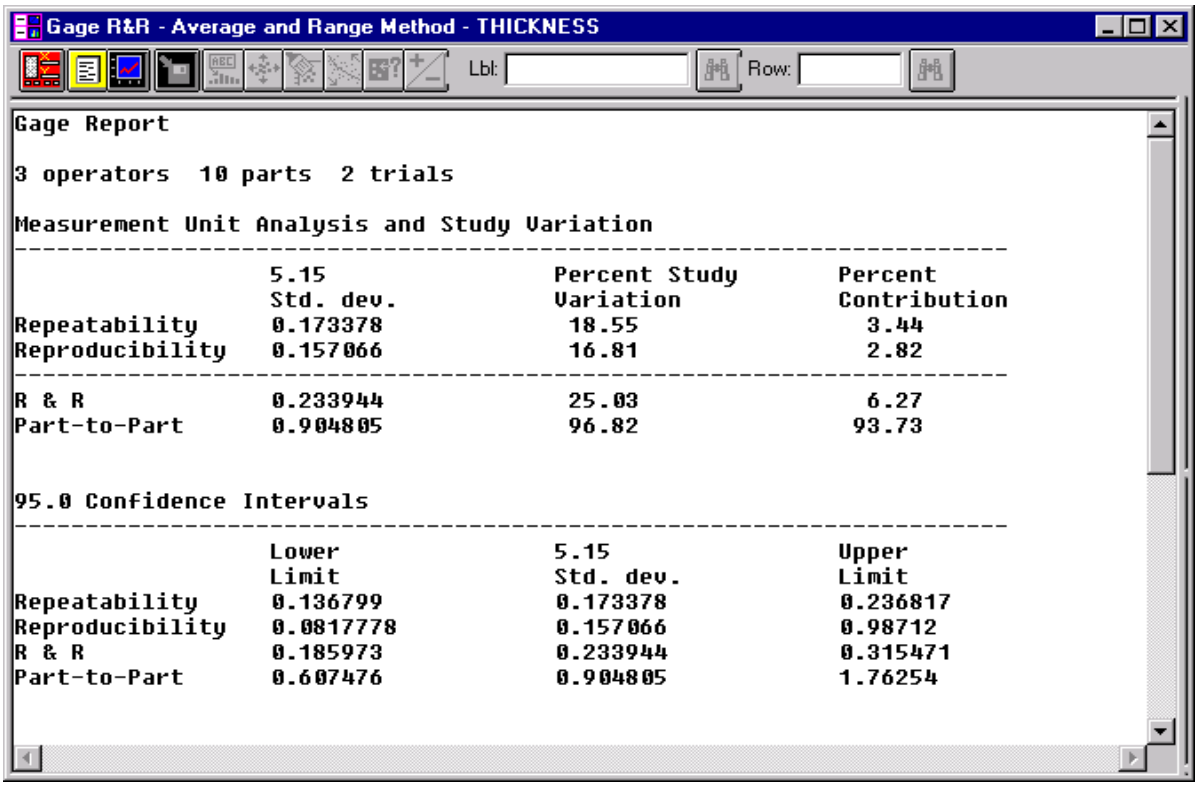


Figure 8-6. Gage Report

Because estimates of variability are subject to sampling error, the confidence intervals show the preciseness of the estimates. Values for percentage of tolerance below 10 percent indicate that a gage is capable. Values above 30 percent indicate that the measurement system needs considerable improvement. Values between 10 percent and 30 percent suggest that you should monitor the measurement system. The table also displays the results of a process sigma analysis if you enter a value for the Estimated Process Sigma.

Graphical Options

Operator and Part Plot

The Operator and Part Plot option creates a multiple-line plot of the average measurement for each part by each operator (see Figure 8-7). The plot helps to determine if there is interaction between the parts and operators. Lines that cross suggest interaction and indicate that the ANOVA Method should be used to analyze the data.

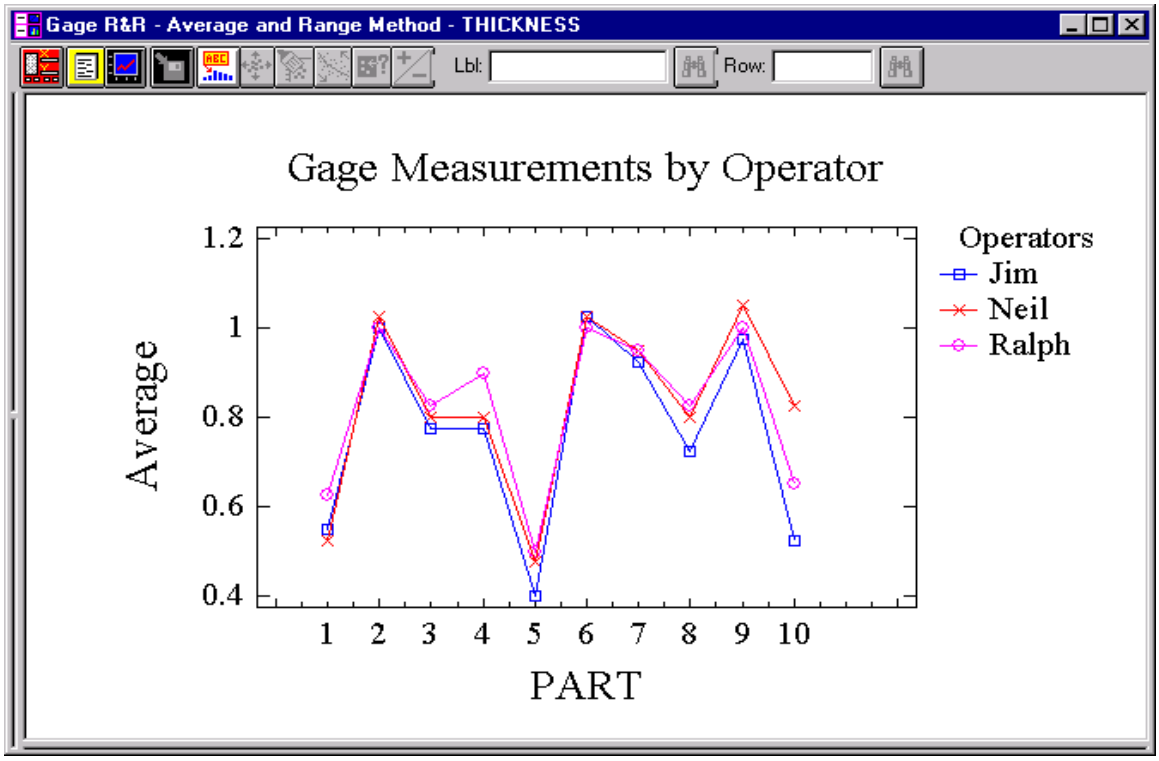


Figure 8-7. Operator and Part Plot

Use the ***Operator and Part Plot Options*** dialog box to indicate if points and/or lines should appear on the plot.

Range Chart by Operator

The Range Chart by Operator option creates a range chart for each group of measurements made by the operators on the parts in the study (see Figure 8-8). The upper limit is placed at the 3-sigma location, which is usual for this chart. The chart is useful for detecting differences in operator variation and out-of-control ranges. The horizontal line represents the average range.

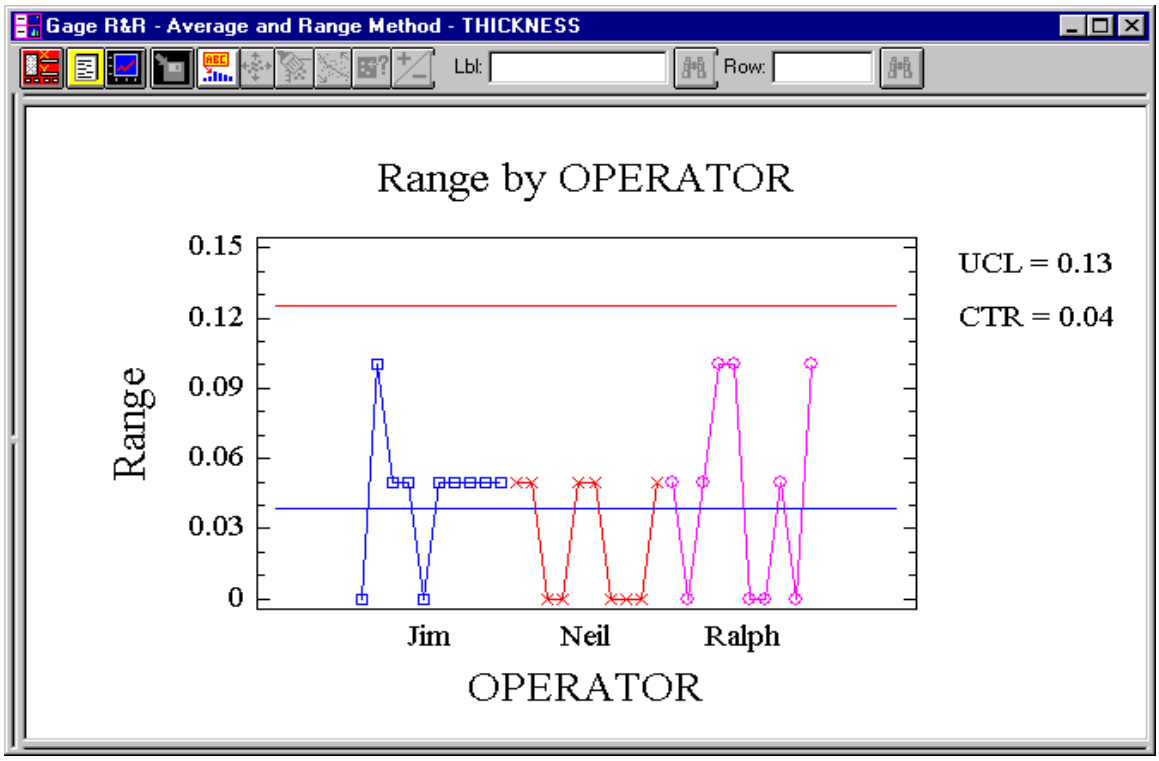


Figure 8-8. Range Chart by Operator

Use the ***Range Chart Options*** dialog box to enter the number of decimal places that should be used for displaying the limits.

Range Chart by Part

The Range Chart by Part option creates a plot of the range for each group of measurements made by the operators on the parts in the study (see Figure 8-9). The upper limit is placed a the 3-sigma location, which is usual for this chart. The vertical line connects the minimum and maximum deviation for each part. The horizontal line represents the average range.

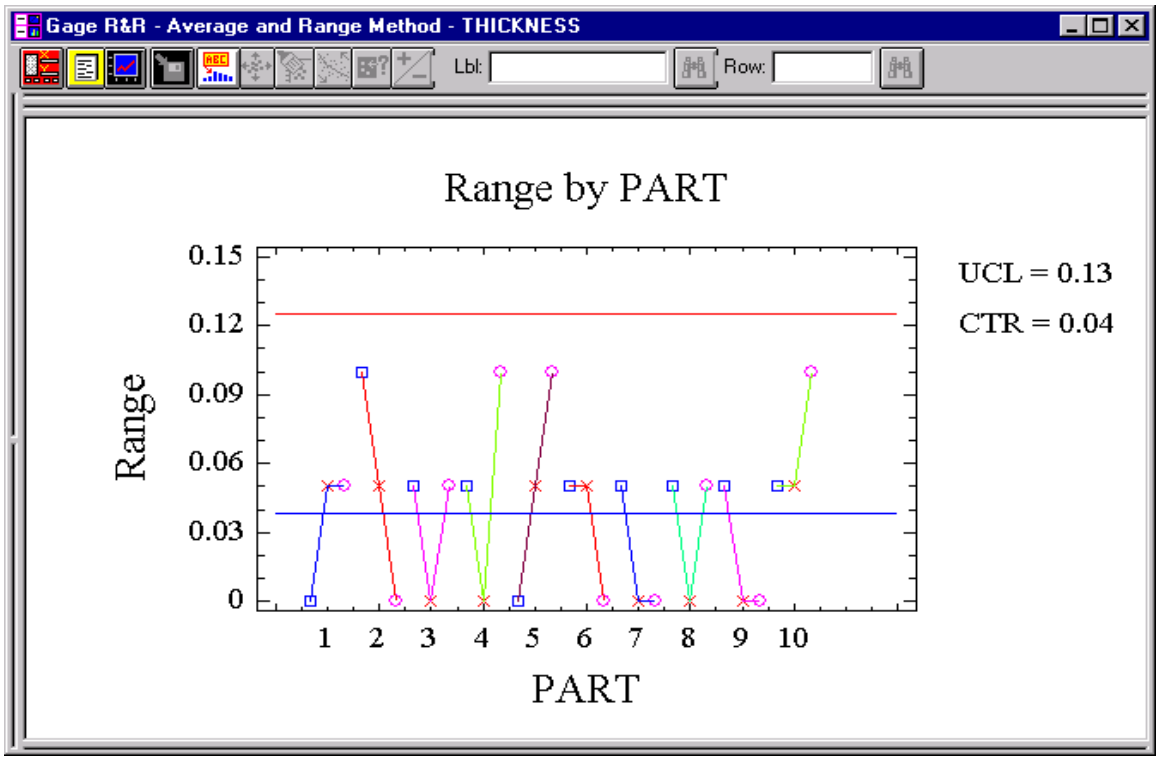


Figure 8-9. Range Chart by Part

Use the ***Range Chart Options*** dialog box to enter the number of decimal places that should be used for displaying the limits.

Box-and-Whisker Plot

The Box-and-Whisker Plot option creates multiple plots, one for each operator (see Figure 8-10). The rectangular part of the plot extends from the lower quartile to the upper quartile, covering the center half of the sample. The centerline within each box shows the location of the sample median. The plus signs indicate the location of the sample means. The whiskers extend from the box to the minimum and maximum values in the sample, except for any outside or far outside points, which are plotted separately.

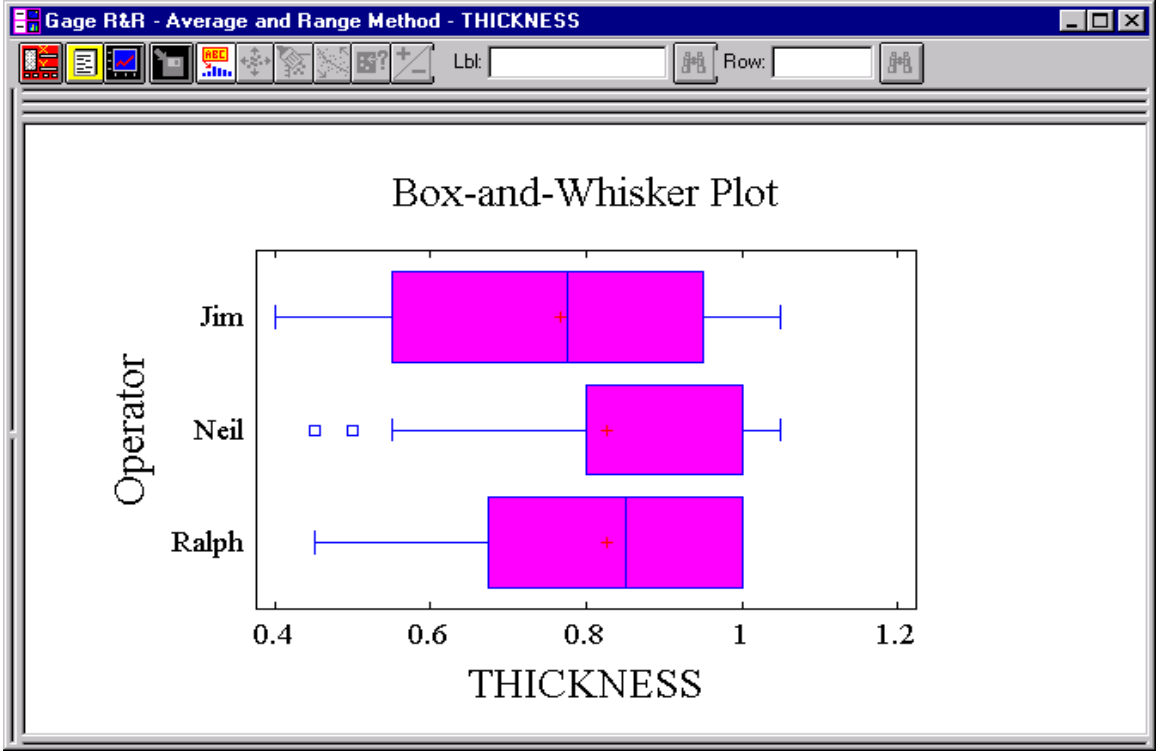


Figure 8-10. Box-and-Whisker Plot

Outside points are points that lie more than 1.5 times the interquartile range above or below the box and are shown as small squares. Far outside points are points that lie more than 3.0 times the interquartile range above or below the box. They are shown as small squares with plus signs through them.

Use the **Box-and-Whisker Plot Options** dialog box to indicate if the direction of the plot will be vertical or horizontal; and to choose the features for the plot: median notch, outlier symbols, or mean marker (see Figure 8-11).

Figure 8-11. Box-and-Whisker Plot Options Dialog Box.

R&R Plot

The R&R Plot option creates a plot that displays a box for each operator and a vertical line within the box for each part measured by that operator (see Figure 8-12). Each point represents the difference between a single measurement and the grand average of all the measurements.

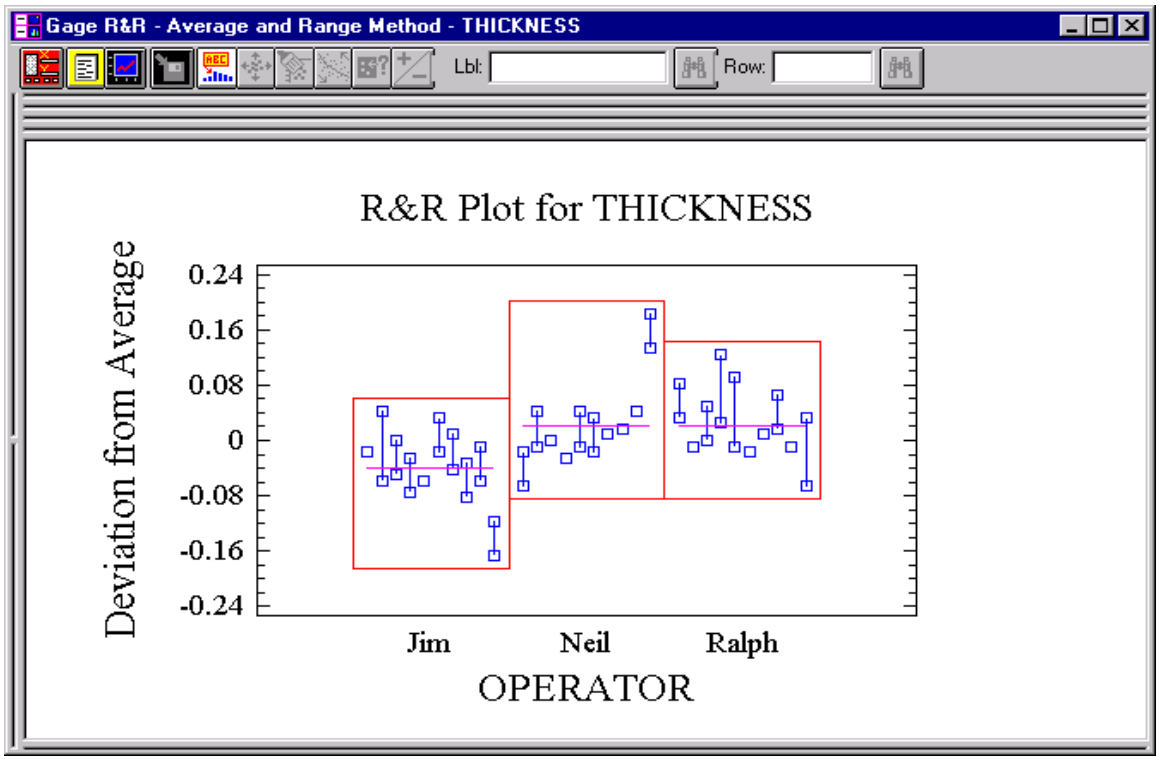


Figure 8-12. R&R Plot

The horizontal line within each box represents the difference between the average measurement for the operator and the grand average. By comparing the heights of the boxes, you can compare the variability for the operators. By comparing the location of the boxes, you can determine if certain operators tend to measure higher or lower than others. The heights of the vertical lines show the repeatability of the measurement process. The box-to-box comparison shows the reproducibility.

Run Chart

The Run Chart option displays the data in sequential order, grouped by operator and part. Any consistent pattern may indicate a change in the gage over the duration of the study. There are no options for this plot.

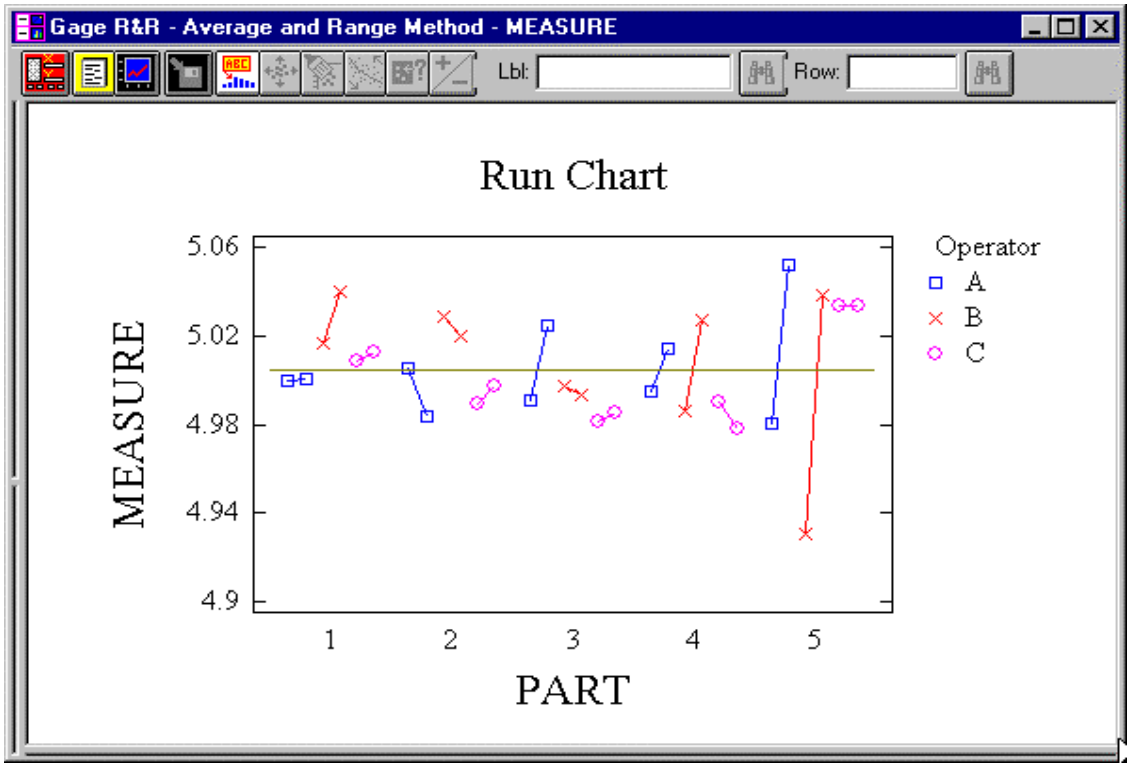


Figure 8-13. Run Chart

Using the ANOVA Method

The ANOVA Method is similar to the Average and Range Method in that it is a full repeatability and reproducibility analysis that involves multiple operators, parts, and replications. It also measures the interaction between operators and parts. The calculations in this method tend to be more accurate than those in the other methods. To use this method, set up variables that contain operator names, part numbers, trial numbers, and measurements. The design must be balanced; that is, each operator must measure each part the same number of times.

To Access the ANOVA Method, choose SPECIAL... QUALITY CONTROL... GAGE R&R... ANOVA METHOD... from the Menu bar to display the ANOVA Method dialog box shown in Figure 8-14. Complete the dialog box and click OK to display the Analysis Summary and the Operator and Part Plot in the Analysis window.

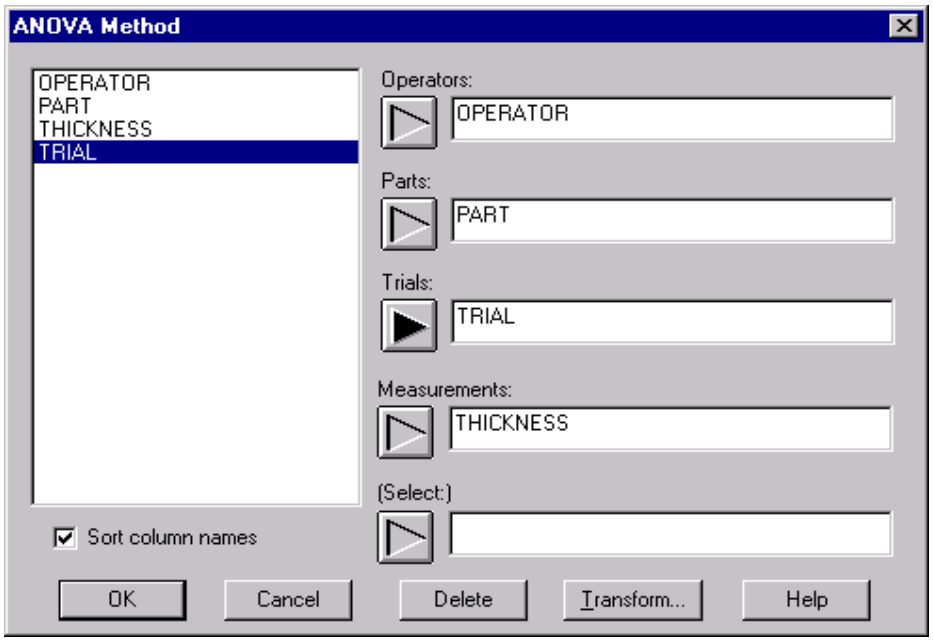


Figure 8-14. ANOVA Method Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis (see Figure 8-15). The summary displays the names of the variables that contain the values for the operators, parts, and trials. The summary also displays the name of the variable that contains the measurements for each combination of operators, parts, and trials.

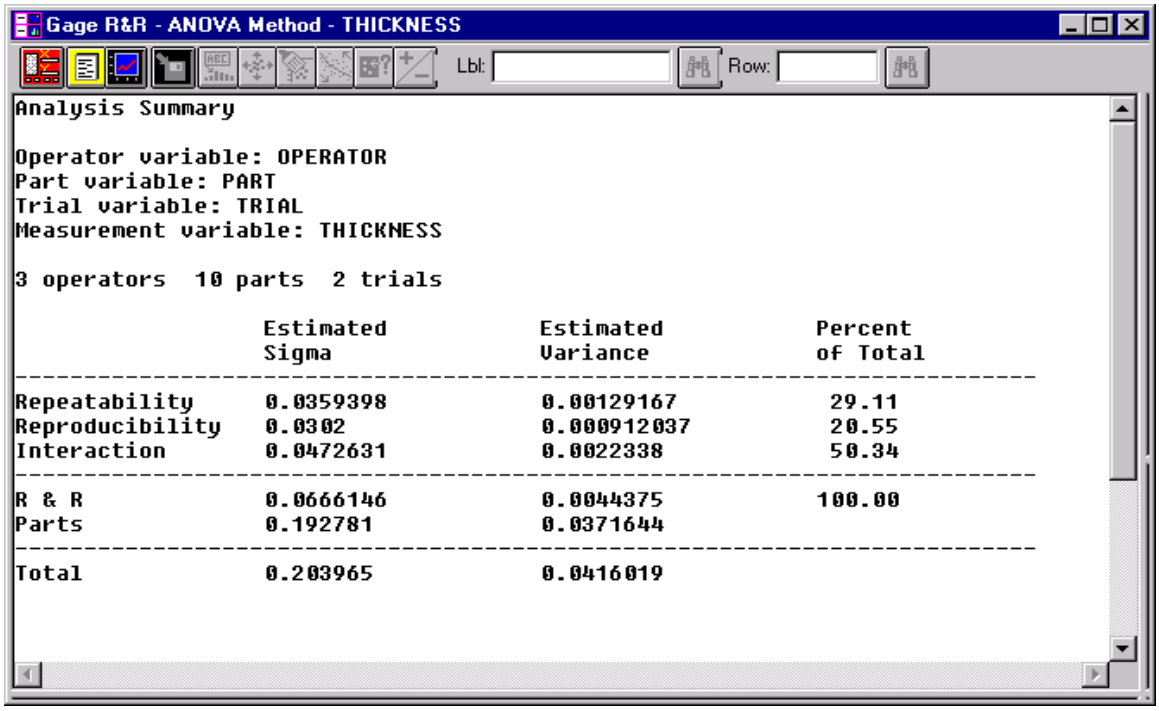


Figure 8-15. Analysis Summary

The table in the summary displays values for the Estimated Sigma, Estimated Variance, and Percent of Total. Estimated Sigma values are the standard deviation for the measures of Repeatability, Reproducibility, a combination of the two (R&R), Parts and Total. Estimated Variance values include the measure of Repeatability, Reproducibility, a combination of the two (R&R), Parts and Total. Percent of Total is the amount of the total estimated variance that can be attributed to repeatability versus reproducibility.

Use the *ANOVA Method Options* dialog box to enter values for the tolerance, sigma intervals, process sigma, and confidence level (see Figure 8-16).

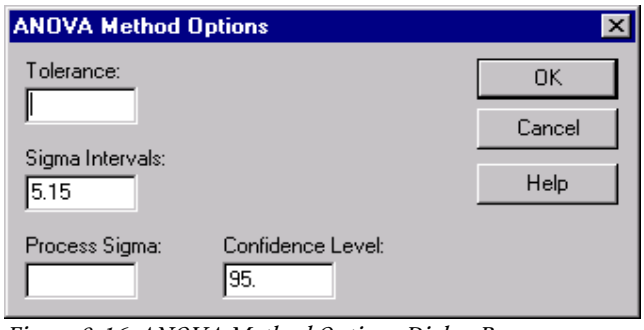


Figure 8-16. ANOVA Method Options Dialog Box

ANOVA Table

The ANOVA Table option creates a standard analysis of variance (ANOVA) table (see Figure 8-17). The ANOVA Table presents the sum of squares statistics, which show the results of measuring the variability for operators, parts, and their

interaction. Each mean square is the sum of squares for the source of variation divided by the degrees of freedom (Df) for the source. The F-Ratio statistic is the mean square of the interaction between the parts and operators divided by the mean squared error. The p-values indicate if the F-Ratio is significantly large; small significance levels (less than 0.05 for most applications) indicate that the interaction between the parts and operators is significant and that the interaction should remain in the analysis.

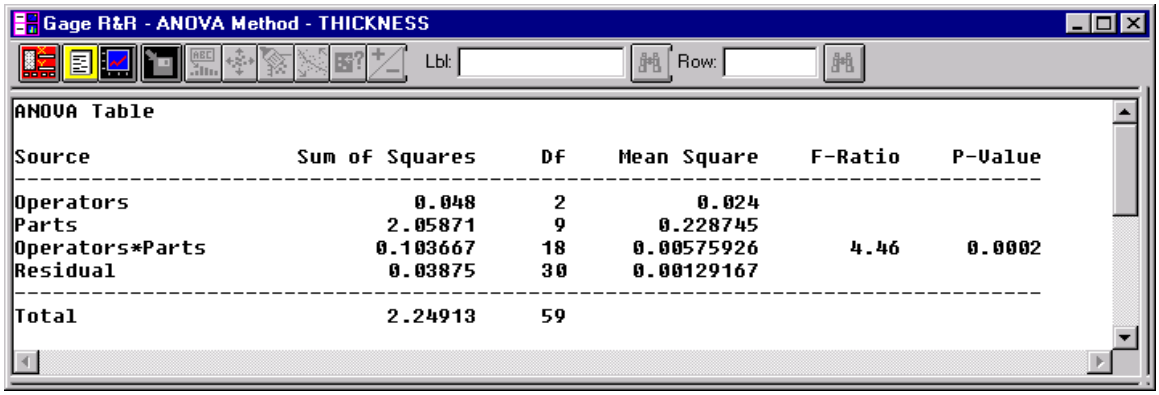


Figure 8-17. ANOVA Table

Use the **Interaction Options** dialog box to indicate if the interaction should be included in the ANOVA table.

Gage Report

The Gage Report option displays the measurement unit analysis, study variation table, and confidence intervals (see Figure 8-18). The table shows the intervals equal to a percentage times the standard deviations due to repeatability, reproducibility, combined R&R, and part-to-part variation. The intervals can be expected to contain a given percentage of the errors attributed to each source.

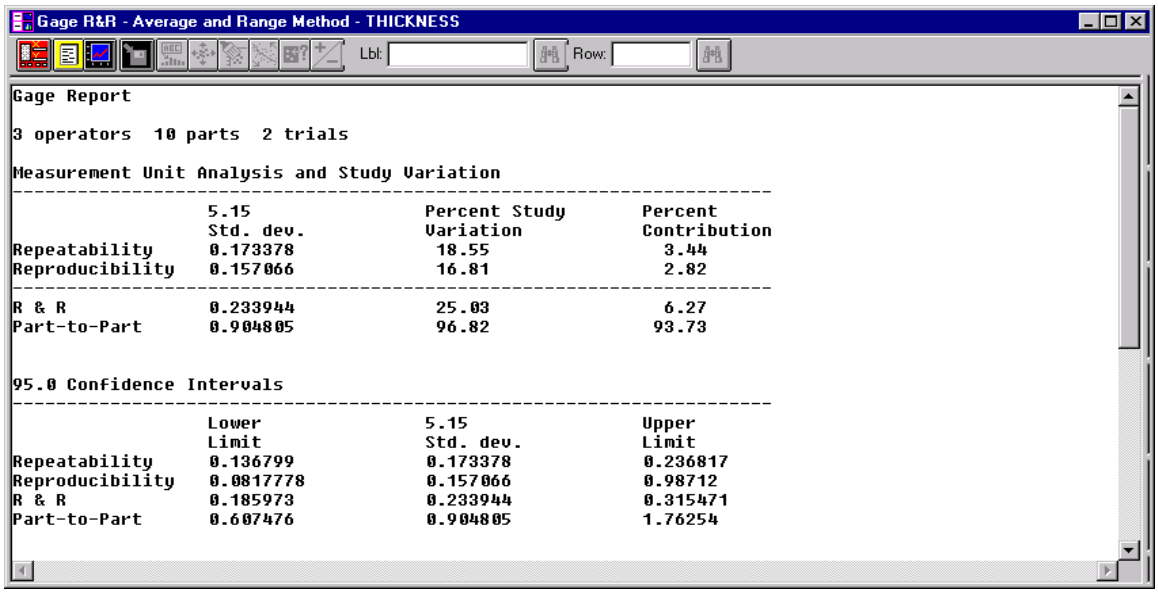


Figure 8-18. Gage Report

Because estimates of variability are subject to sampling error, the confidence intervals show the preciseness of the estimates. Values for percentage of tolerance below 10 percent indicate that a gage is capable. Values above 30 percent indicate that the measurement system needs considerable improvement. Values between 10 percent and 30 percent suggest that you should monitor the measurement system. The table also displays the results of a process sigma analysis if you enter a value for the Estimated Process Sigma.

Graphical Options

Operator and Part Plot

The Operator and Part Plot option creates a multiple-line plot of the average measurement for each part by each operator (see Figure 8-19). The plot helps to determine if there is interaction between the parts and operators. Lines that cross suggest interaction and indicate that the ANOVA Method should be used to analyze the data.

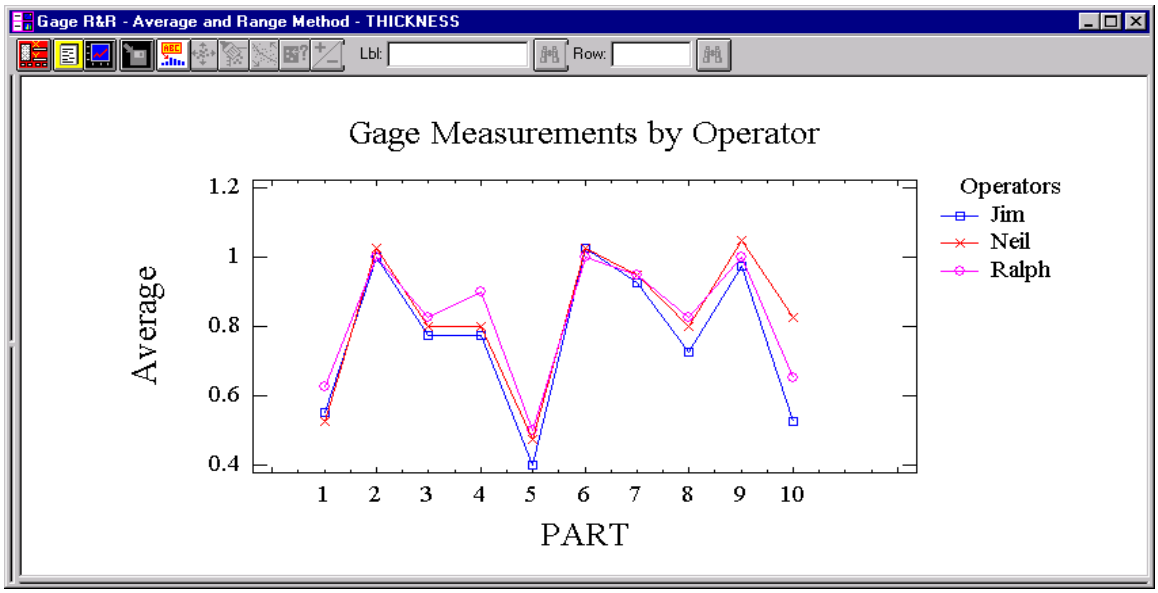


Figure 8-19. Operator and Part Plot

Use the ***Operator and Part Plot Options*** dialog box to indicate if points and/or lines will appear on the plot.

Box-and-Whisker Plot

The Box-and-Whisker Plot option creates multiple plots, one for each operator (see Figure 8-20). The rectangular part of the plot extends from the lower quartile to the upper quartile, covering the center half of the sample. The centerline within each box shows the location of the sample median. The plus signs indicate the location of the sample means. The whiskers extend from the box to the minimum and maximum values in the sample, except for any outside or far outside points, which are plotted separately.

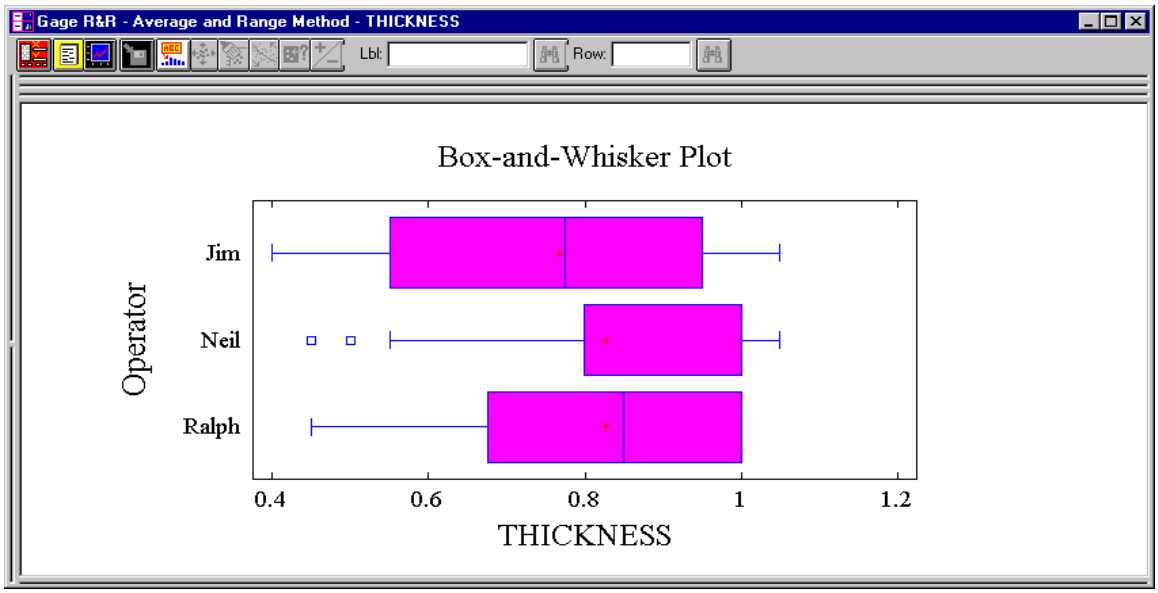


Figure 8-20. Box-and-Whisker Plot

Outside points are points that lie more than 1.5 times the interquartile range above or below the box and are shown as small squares. Far outside points are points that lie more than 3.0 times the interquartile range above or below the box. They are shown as small squares with plus signs through them.

Use the ***Box-and-Whisker Plot Options*** dialog box to indicate if the direction of the plot will be vertical or horizontal; and to choose the features for the plot: median notch, outlier symbols, or mean marker. See Figure 8-11 for an example of this dialog box.

R&R Plot

The R&R Plot option creates a plot that displays a box for each operator and a vertical line within the box for each part measured by that operator (see Figure 8-21). Each point represents the difference between a single measurement and the grand average of all the measurements.

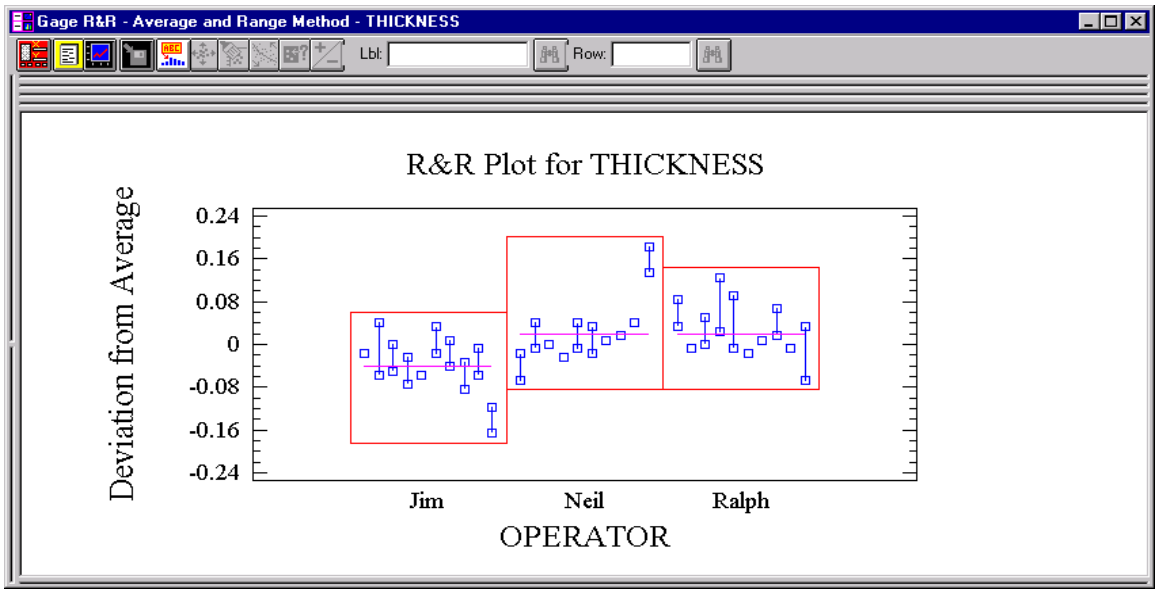


Figure 8-21. R&R Plot

The horizontal line within each box represents the difference between the average measurement for the operator and the grand average. By comparing the heights of the boxes, you can compare the variability for the operators. By comparing the location of the boxes, you can determine if certain operators tend to measure higher or lower than the others. The heights of the vertical lines show the repeatability of the measurement process. The box-to-box comparison shows the reproducibility.

Run Chart

The Run Chart option displays the data in sequential order, grouped by operator and part. Any consistent pattern may indicate a change in the gage over the duration of the study (see Figure 8-13). There are no options for this plot.

Using the Range Method

The *Range Method* is a quick analysis that involves only two operators who each make one measurement on two or more parts. In this analysis, you cannot separate repeatability and reproducibility.

To Access the Range Method choose SPECIAL... QUALITY CONTROL... GAGE R&R... RANGE METHOD... from the Menu bar to display the Range Method dialog box shown in Figure 8-22. Complete the dialog box and click OK to display the Analysis Summary and the Operator and Part Plot in the Analysis window.

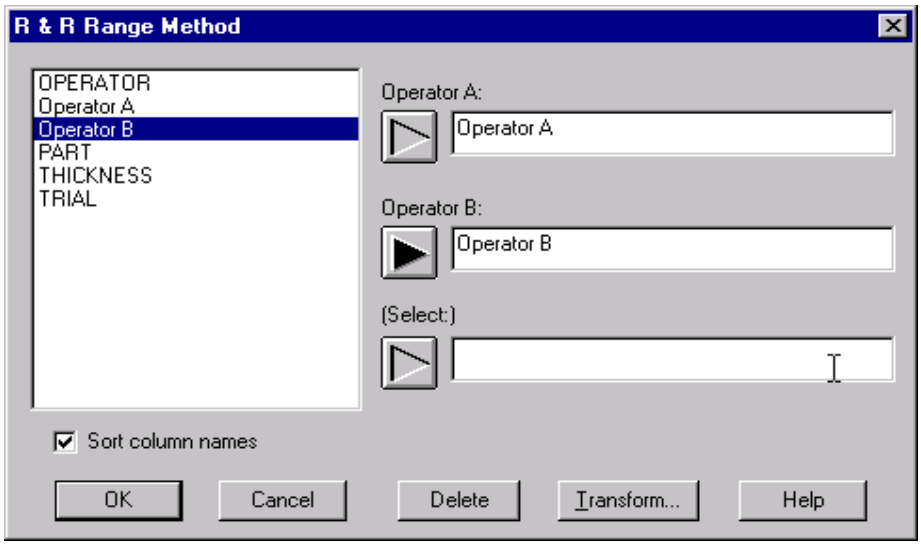


Figure 8-22. Range Method Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the analysis that displays the names of the variables, the number of parts, the mean range, and the estimated R&R sigma and variance for the combined R&R (see Figure 8-23).

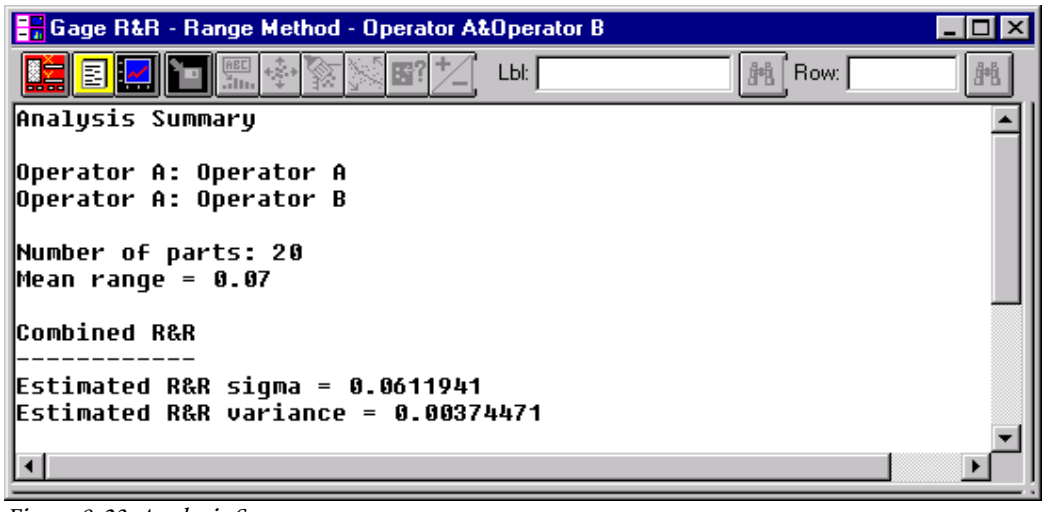


Figure 8-23. Analysis Summary

The average range is for all the trials, while the estimated R&R sigma is the estimated R&R in standard deviations, and the estimated R&R variance is the estimated variance. If you enter a value for the tolerance of the parts (the USL minus the LSL), the summary also includes these statistics. The other statistics are the results of the number of standard deviations (sigma intervals) and the estimated sigma. The Percent of Tolerance statistics are the values that result when the values in the R&R measurements are divided by the tolerance value and multiplied by 100. The Sigma Intervals represent the number used to obtain the Gage R&R Percent of Tolerance values. Tolerance is the total tolerance width from the part specifications. This value is used as a denominator when the percentage tolerance is calculated for a combined Gage R&R.

Use the ***Range Method Options*** dialog box to enter values for the tolerance and sigma intervals (see Figure 8-24).

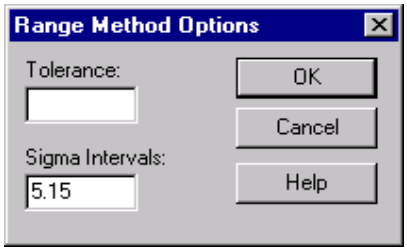


Figure 8-24. Range Method Options Dialog Box

Graphical Options

Operator and Part Plot

The Operator and Part Plot option creates a multiple line plot of the average measurement for each part by each operator (see Figure 8-25). This plot helps determine if there is interaction between the parts and the operators. If the lines cross, the plot suggests an interaction. If there is an interaction, a larger study is indicated.

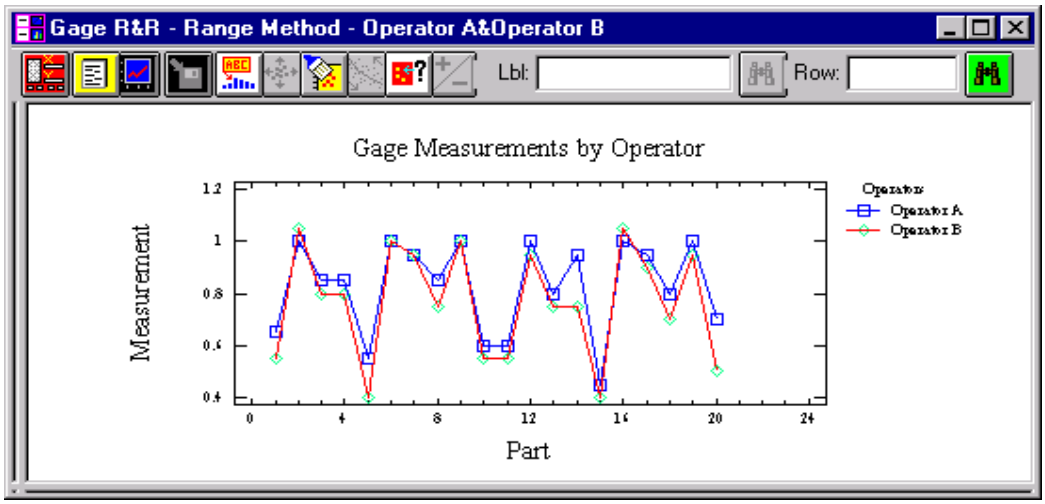


Figure 8-25. Operator and Part Plot

Use the **Operator and Part Plot Options** dialog box to indicate if points and/or lines should appear on the plot.

Range Chart by Part

The Range Chart by Part option creates a chart that shows the range of measurements made by the two operators on the parts (see Figure 8-26). The upper limit is placed at the usual 3 sigma location for a Range chart. Groups appearing beyond the control limit imply the variability is not in control.

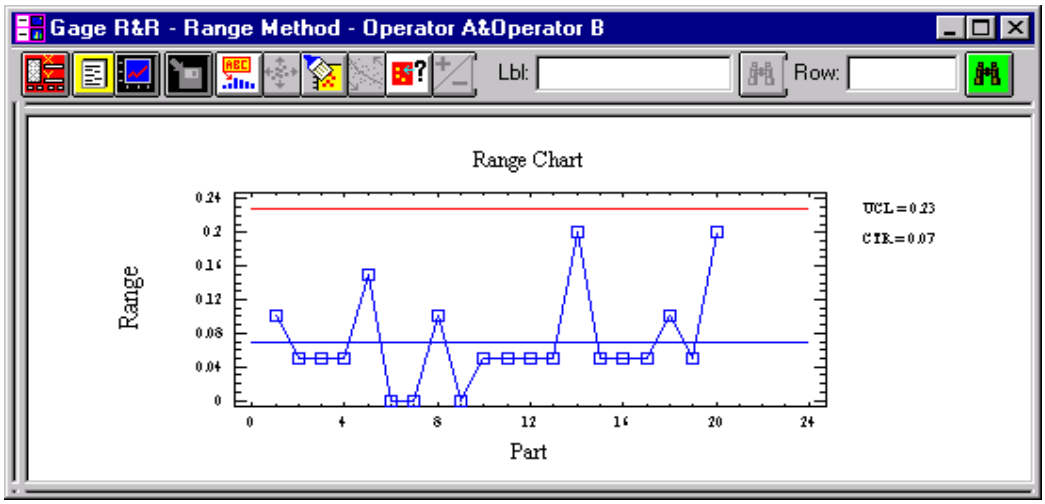


Figure 8-26. Range Chart by Part

Box-and-Whisker Plot

The Box-and-Whisker Plot option creates multiple plots, one for each operator (see Figure 8-27). The rectangular part of the plot extends from thelower quartile to the upper quartile, covering the center half of the sample. The centerline within each box shows the location of the sample median. The plus signs indicate the location of the sample means. The whiskers extend from the box to the minimum and

maximum values in the sample, except for any outside or far outside points, which are plotted separately.

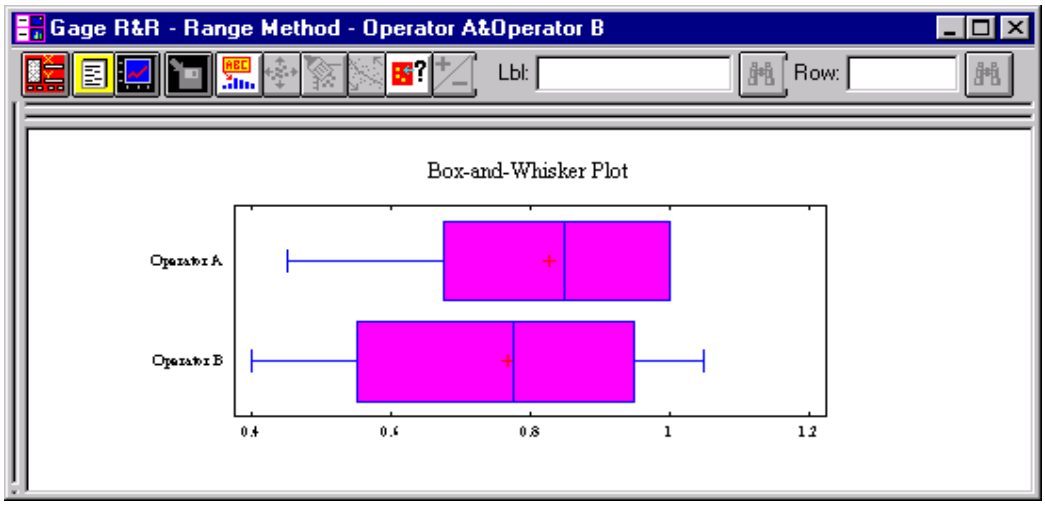


Figure 8-27. Box-and-Whisker Plot

Outside points are points that lie more than 1.5 times the interquartile range above or below the box and are shown as small squares. Far outside points are points that lie more than 3.0 times the interquartile range above or below the box. They are shown as small squares with plus signs through them.

Use the ***Box-and-Whisker Plot Options*** dialog box to indicate if the direction of the plot will be vertical or horizontal; and to choose the features for the plot: median notch, outlier symbols, or mean marker. See Figure 8-11 for an example of this dialog box.

References

AIAG. 1990. **Measurement Programs Analysis Reference Manual**. Troy, Michigan: AIAG.

Duncan, A. J. 1974. **Quality Control and Industrial Statistics,** fourth edition**.** Homewood, Illinois: Richard D. Irwin, Inc.

Montgomery, D. C. 1997**. Introduction to Statistical Quality Control,** third edition. New York: Wiley & Sons. Irwin, Inc.

Chapter 9

USING THE CUSTOM CHART ANALYSIS

The Custom Chart Analysis allows you to create charts with custom titles, scaling, and horizontal and vertical lines. Its primary purpose is to create charts that can be used to overlay other plots when the StatGallery is used. You can also create quality control chart templates for monitoring processes.

For example, if you are trying to determine if a dispensing machine that fills boxes is in statistical control, supervisors on the plant floor might be asked to collect the data on the weight dispensed into a sample of boxes. To ensure that all the supervisors chart the data the same way, you create a blank chart that all the supervisors can use to plot the data.

To Access the Custom Chart Analysis

1. Choose SPECIAL... QUALITY CONTROL... CUSTOM CHART... from the Menu bar to display the Custom Chart Analysis dialog box shown in Figure 9-1.

2. Complete the dialog box, then click OK to display the Analysis Summary and Custom Chart in the Analysis window.

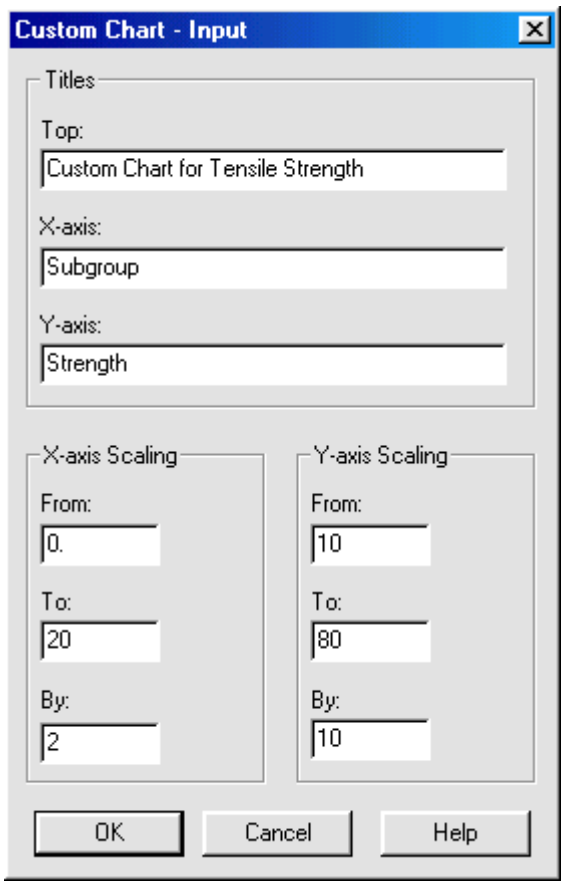


Figure 9-1. Custom Chart Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates instructions for customizing a chart (see Figure 9-2).

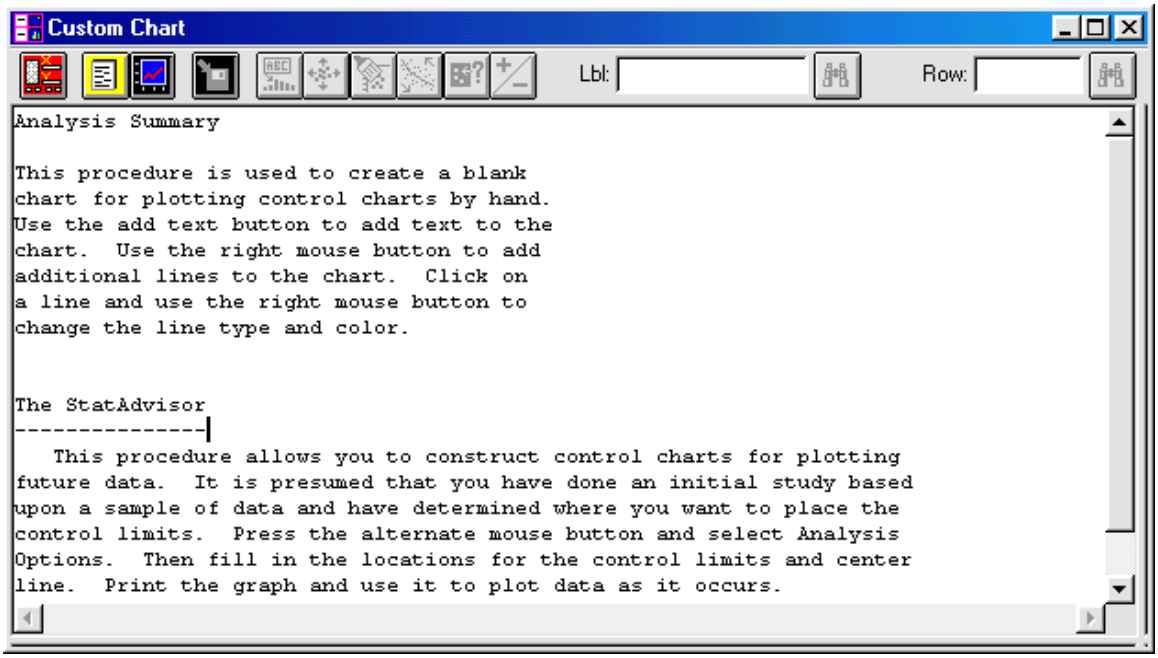


Figure 9-2. Analysis Summary

Use the *Custom Chart Analysis Options* dialog box to choose the position and direction for up to eight lines on a customized chart (see Figure 9-3).

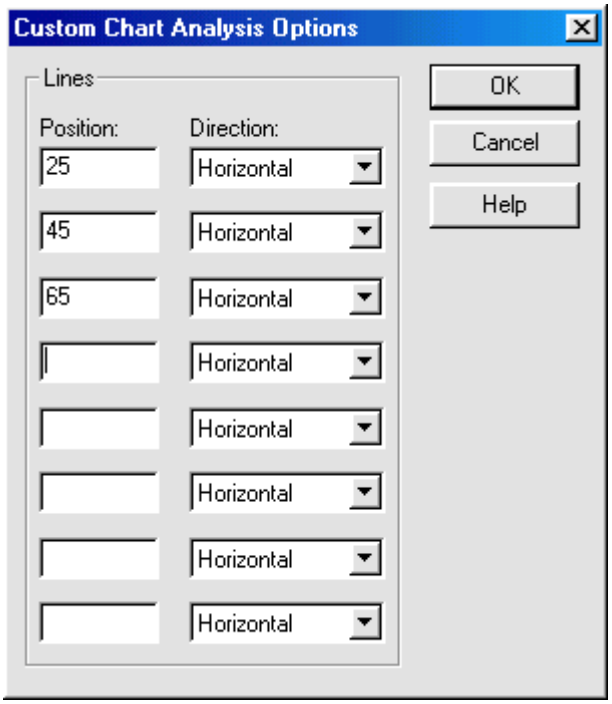


Figure 9-3. Custom Chart Analysis Options Dialog Box

Graphical Options

Custom Chart

The Custom Chart option creates a customized chart that contains the selected titles and axis scaling (see Figure 9-4).

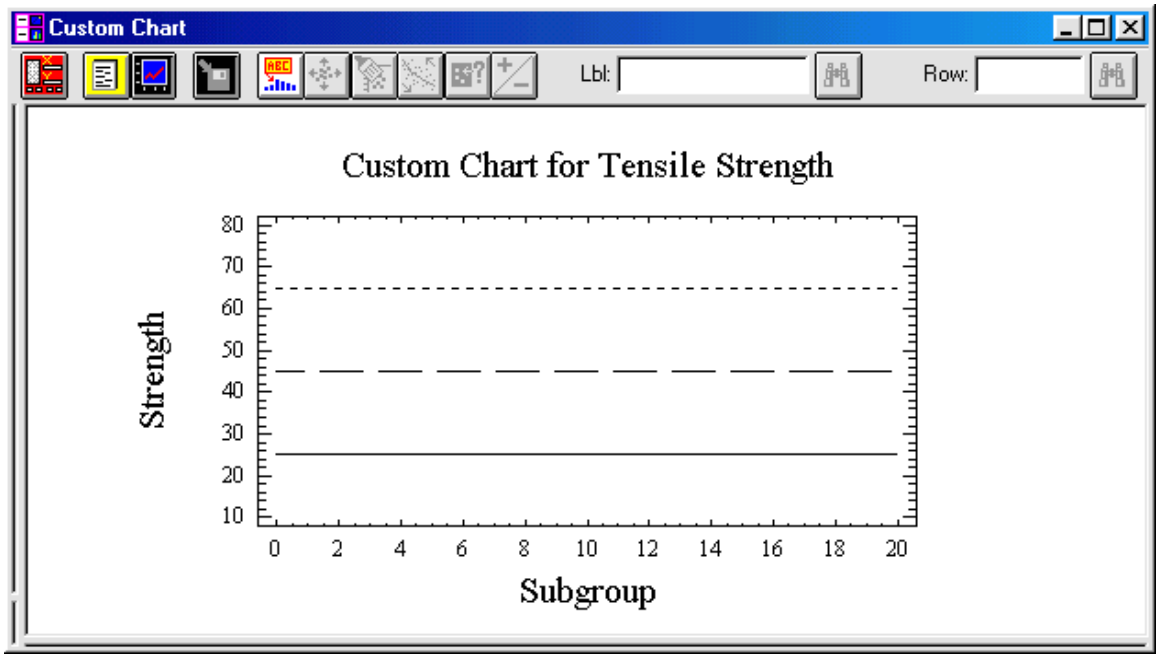


Figure 9-4. Custom Chart

Use the *Custom Chart Analysis Options* dialog box to change the position and direction of the lines on the chart.

References

Johnson, N. L. and Kotz, S. 1970. *Continuous Univariate Distributions - 1.* New York: Wiley.

Chapter 10

USING THE FISHBONE DIAGRAM ANALYSIS

After a defect, error, or problem is identified and isolated for further study, manufacturing personnel must analyze the potential causes of the undesirable effect (Montgomery, 1997). A Fishbone Diagram, also known as a cause and effect diagram, is often constructed by a quality-improvement team responsible for dissecting a problem or process. Doing this in a brainstorming session, forces team members to organize their thoughts and provide a plan of action at the same time.

Montgomery (1997) suggests that these diagrams be constructed following a seven-step plan:

1. Define the problem or effect to be analyzed.

2. Form the team that will perform the analysis.

3. Draw the effect box and the center line.

4. List the major potential cause categories and join them as boxes connected to the center line.

5. Identify the possible causes and classify them into the categories in Step 4; create new categories, if necessary.

6. Rank order the causes to identify those that seem most likely to impact the problem.

7. Take corrective action.

A noted Japanese quality expert, Dr. Kaoru Ishikawa, originally developed the diagram for solving quality problems. A major benefit of the diagram is that it forces all that is known about a subject to be noted, which is also a major weakness because its accuracy depends on the person or group who creates the diagram. It is critical that input be gathered from everyone involved with the process because the varying ideas often lead to a better picture of the actual causes.

There are other benefits for using this type of diagram.

- All the factors are known, instead of only those suspected.

- The diagram provides a plan of attack that allows deletion of causes that may not turn out to be important.

- The diagram provides an ongoing record of when the actual relationships occur and when they are corrected.

- When the analysis is complete, it is reasonable to assume that you have accounted for all the information.

Setting Up a DataSheet for Creating a Fishbone Diagram

STATGRAPHICS *Plus* lets you create a Fishbone Diagram using the computer rather than pencil and paper; however, you must know how to correctly enter the data.

1. Access a blank untitled DataSheet.

2. Access the Modify Column dialog box, and define a single character column with a width adequate for the labels you will be entering.

3. Enter primary-cause category names flush with the left edge of the column. Enter rank-ordered, secondary-cause categories with a beginning period (.) preceding the name; and enter rank-ordered, tertiary-cause categories with double periods (..) preceding the name.

For an example of a DataSheet set up this way, see Figure 10-1. After you create the diagram, you can use the graphics editing options to change its look. For example, you could change the primary-cause category names to a larger point size, make them bold, or change their color to make them stand out. You can also move the labels to provide more or less white space.

Fishbone Diagram.sf3

	Cause and Effects	Col_2	Col_3
1	Defects in Printed Circuit Board		
2	Raw Card		
3	.Moisture Content		
4	..Time		
5	..Temperature		
6	.Short Circuit		
7	.Shroud		
8	Solder Process		
9	.Flux		
10	.Temperature		
11	..Setup		
12	..Control		
13	.Splatter		
14	.Chain Speed		

Figure 10-1. DataSheet Set Up for a Fishbone Diagram Analysis

To Access the Fishbone Diagram Analysis

1. Choose SPECIAL... QUALITY CONTROL... FISHBONE DIAGRAM... from the Menu bar to display the Fishbone Diagram dialog box shown in Figure 10-2.

2. Complete the dialog box and click OK to display the Analysis Summary and Fishbone Diagram in the Analysis window.

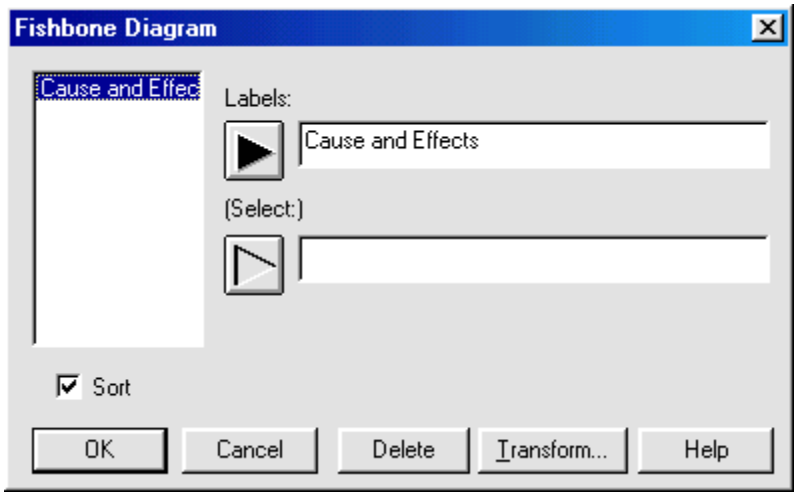


Figure 10-2. Fishbone Diagram Analysis Dialog Box

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary that shows the name of the variable that contains the label names, the name of the effect, and the number of primary, secondary, and tertiary causes (see Figure 10-3).

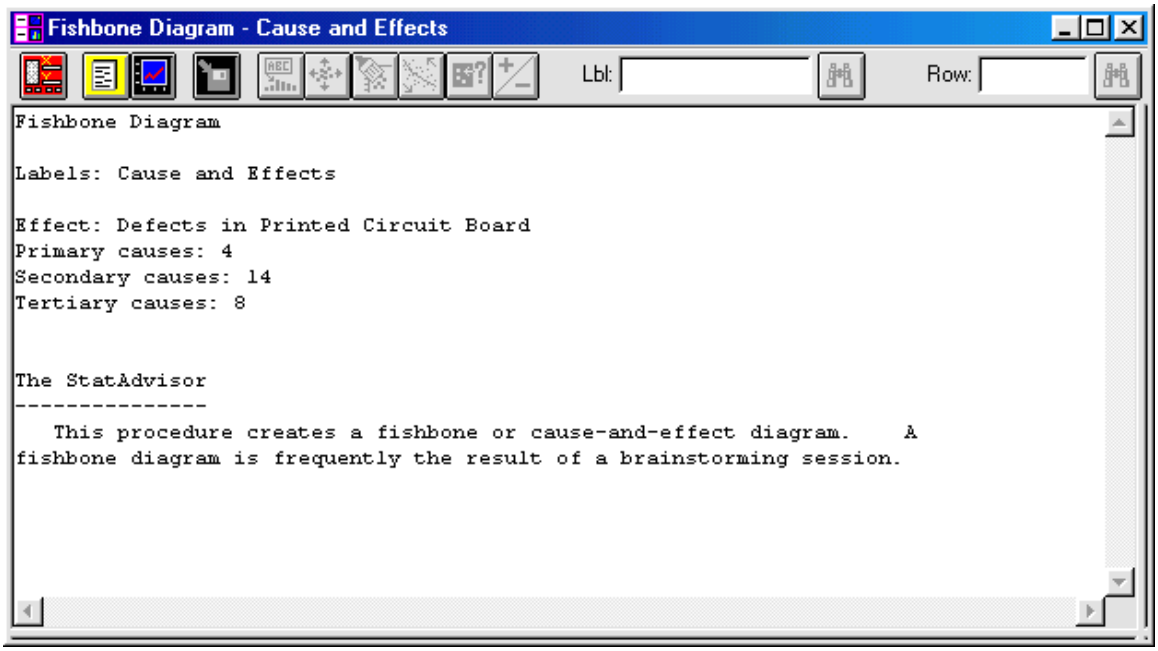


Figure 10-3. Analysis Summary

Graphical Options

Fishbone Diagram

The Fishbone Diagram option displays a cause-and-effect diagram that shows the name of the effect and the primary, secondary, and tertiary causes (see Figure 10-4).

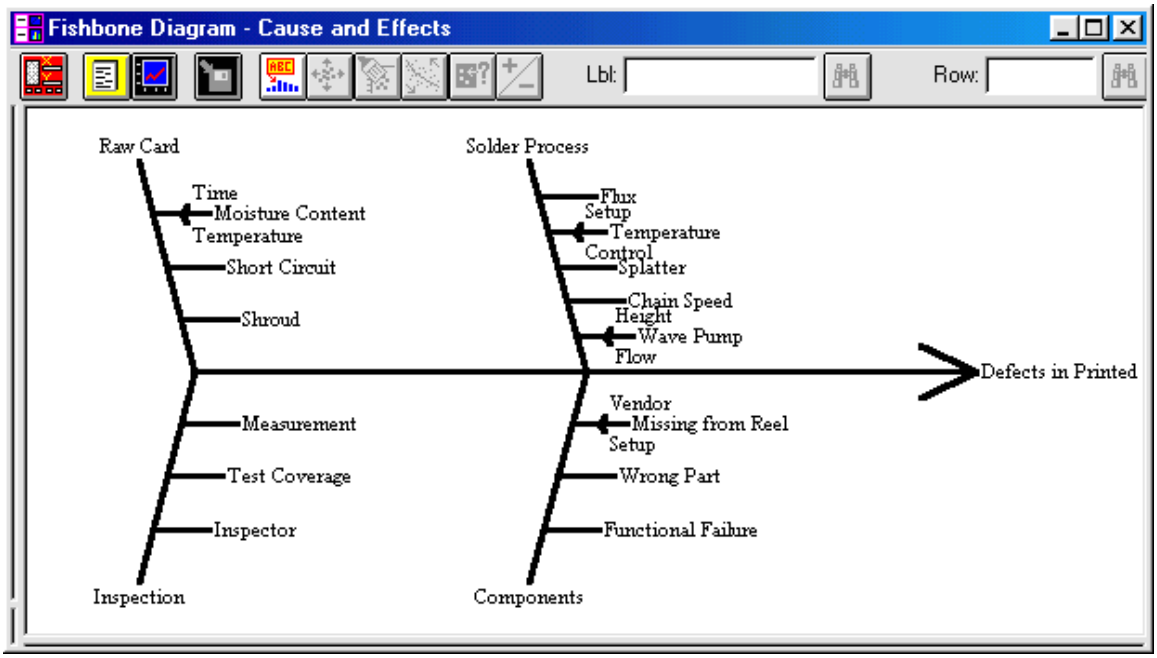


Figure 10-4. Fishbone Diagram

Chapter 11

USING ACCEPTANCE SAMPLING ANALYSES

There are several ways to categorize acceptance-sampling plans; however, the most common is by variables and attributes. Montgomery (1997) defines variables as ″quality characteristics that are measured on a numerical scale″; and attributes as ″quality characteristics that are expressed on a go/no-go basis.″ STATGRAPHICS *Plus* contains tools that let you create and use both types.

Acceptance sampling is a procedure used to inspect raw materials, semi-finished, and finished products to accept or reject a product, based on adherence to a standard. The underlying philosophy is that acceptance sampling is not a substitute for adequate process controls. In fact, the successful use of process-control techniques at the early stages of manufacturing can greatly reduce and, in some cases, eliminate the need for extensive sampling inspection (Montgomery, 1997).

Acceptance sampling does not lead to process improvement unless causes for rejected lots are found and corrected. Rather, its purpose is for use as an auditing-process tool to sentence lots, not to estimate the proportion of bad items produced by the process.

You would use acceptance sampling when:

- inspection destroys the product
- handling is likely to induce the defects
- time will not permit 100 percent inspection
- inspection costs will be high
- misjudgment costs will be low.

In quality inspection, using the acceptance sampling approach is likely to cause two types of errors: rejection of a good lot and acceptance of a bad lot.

Acceptance sampling requires the selection of a sampling plan, which will determine the size of a sample and the number of defects permitted in the sample.

This chapter discusses both acceptance sampling plans for attributes and for variables.

- Acceptance Sampling by Attributes, where n items are sampled and each is classified as either defective or not defective. Every item is inspected, and replaced if it is defective.

- Acceptance Sampling by Variables, where n items are sampled, and a measurement is made on each one. If the sample mean is closer than a distance, k, to a specification limit, the entire lot is rejected.

Both analyses work the same way: First a sample of size n is taken from a lot of size N, and each item is inspected, or in the case of sampling by variables, measured. Then, based on the sample, the entire lot is either:

- Accepted as is.

- Rejected. If the lot is rejected, you can return the rejected lots to the vendor or you can subject the lot to 100 percent inspection, where every item is inspected and replaced if it is defective.

Using the Acceptance Sampling by Attributes Analysis

Acceptance sampling for attributes includes developing sampling plans for attribute data based on the Binomial and Poisson distributions. The metric for the Operating Curve (OC) can be either the fraction defective, as in the Binomial case of Go/No-Go data, or counts, as in the Poisson case of defect count.

The Acceptance Sampling for Attributes Analysis has several useful applications. It can:

- determine if a process can meet a proposed quality requirement

- determine the required inspection effort

- improve tough recall decisions

- calculate one- and two-sided confidence limits based on fraction defectives and counts.

A description of standard sampling procedures for inspection by attributes that were developed during World War II are discussed in Montgomery (1997) and are the basis for the Acceptance Sampling by Attributes Analysis in STATGRAPHICS *Plus*. Today the most widely used version of the standard is MIL STD 105E and its civilian counterpart standard ANSI/ASQC Z14, which is quite similar.

To Access the Acceptance Sampling - Attributes Analysis

1. Choose SPECIAL... QUALITY CONTROL... ACCEPTANCE SAMPLING... ATTRIBUTES... from the Menu bar to display the Analysis dialog box shown in Figure 11-1.

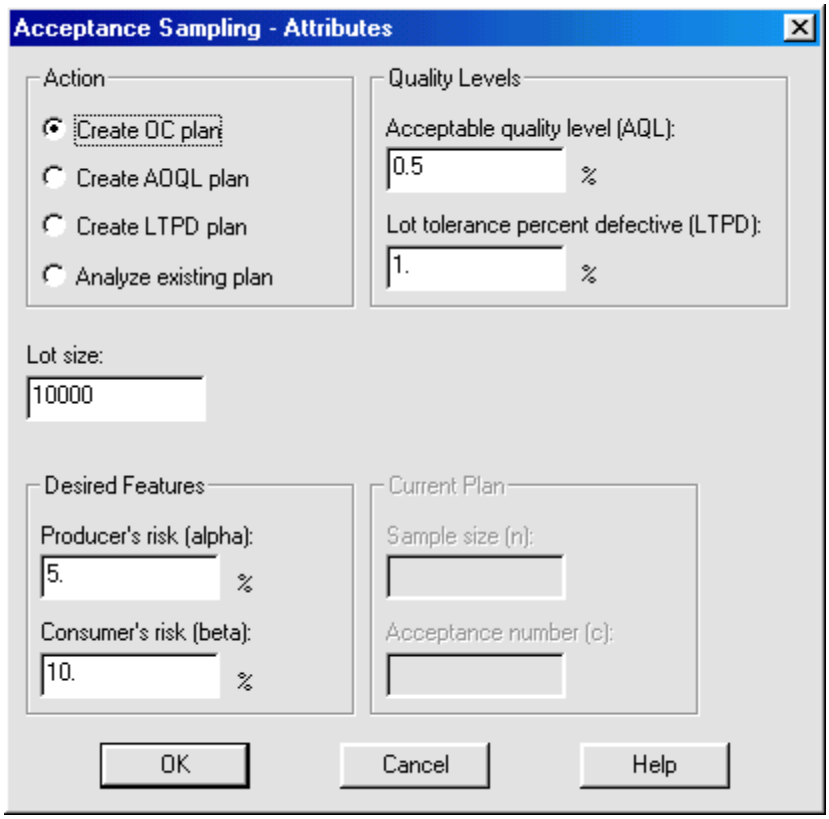


Figure 11-1 Acceptance Sampling Attributes Analysis Dialog Box

2. Complete the dialog box and click OK to display the Analysis Summary and the OC Curve in the Analysis window.

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the sampling plan (see Figure 11-2). A summary of the desired features is created, depending on the type of plan you choose. The summary shows the lot size, desired features, generated plan, and the plan attributes.

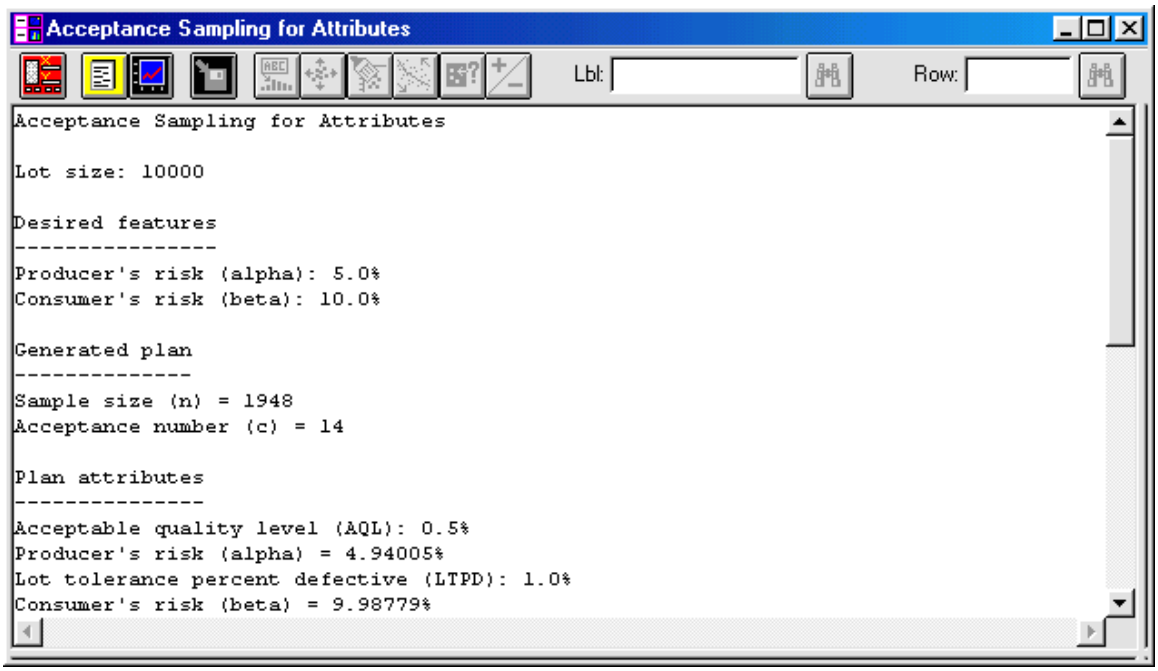


Figure 11-2. Analysis Summary

The Desired Features list includes the producer and consumer risk (alpha and beta), respectively, in percentages. The Generated Plan includes the sample size and the acceptable number of defective items (c). The values for the Plan Attributes include the Acceptable Quality Level (AQL), the Producer's Risk (alpha), the Lot Tolerance Percent Defective (LTPD), and the Consumer's Risk (beta), all in percentages. Also shown are values for the Average Outgoing Quality Limit (AOQL), and the Average Total Inspection (ATI) at units per lot at the AQL, units per lot at the AOQL, and units per lot at the LTPD.

Graphical Options

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability of accepting the lot when using the sampling plan as a function of the true percentage of defective items in the lot (see Figure 11-3). The plot helps determine the adequacy of the current sampling plan.

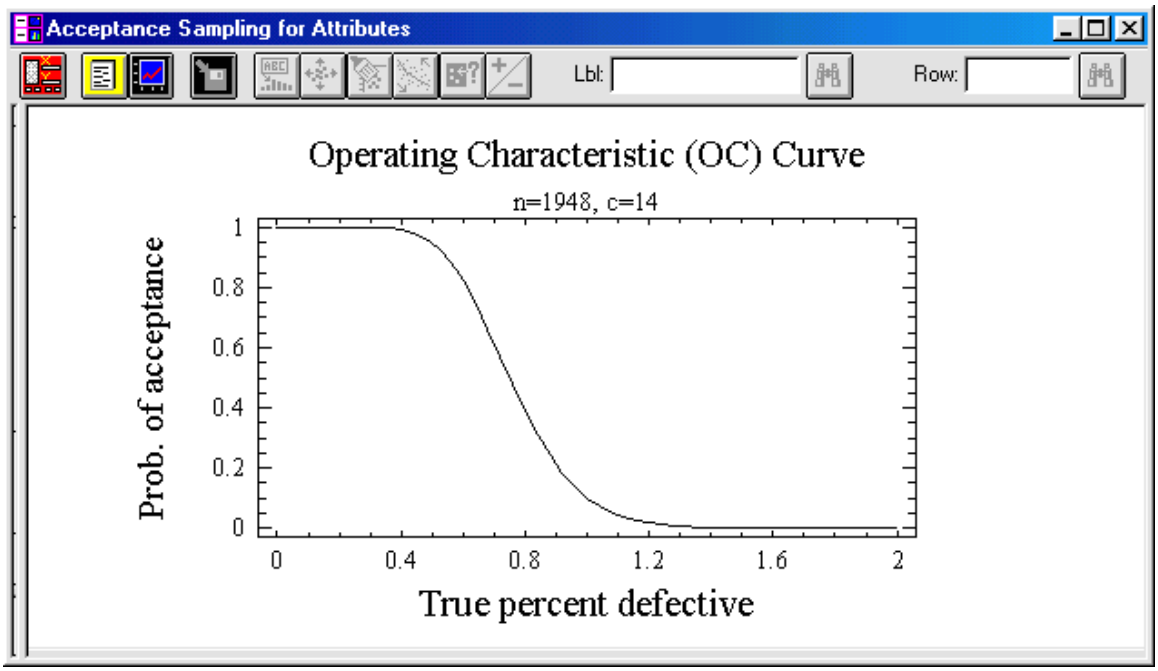


Figure 11-3. OC Curve

AOQ Curve

The AOQ (Average Outgoing Quality) Curve option creates a plot that shows the average percentage of defective items shipped when using the sampling plan (assuming the rejected lots are subjected to 100 percent inspection) as a function of the true percentage of defective items in the lot (see Figure 11-4).

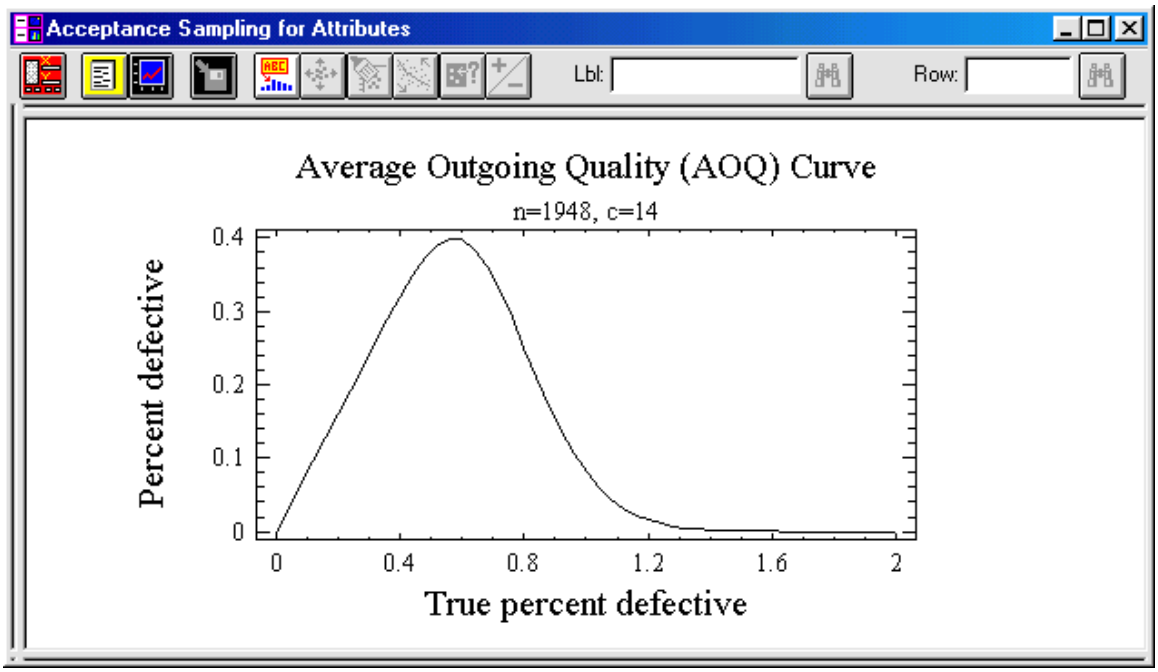


Figure 11-4. AOQ Curve

ATI Curve

The ATI (Average Total Inspection) Curve option creates a plot that shows the average number of units inspected when using the sampling plan (assuming that the rejected lots are subjected to 100 percent inspection) as a function of the true percentage of defective items in the plot (see Figure 11-5).

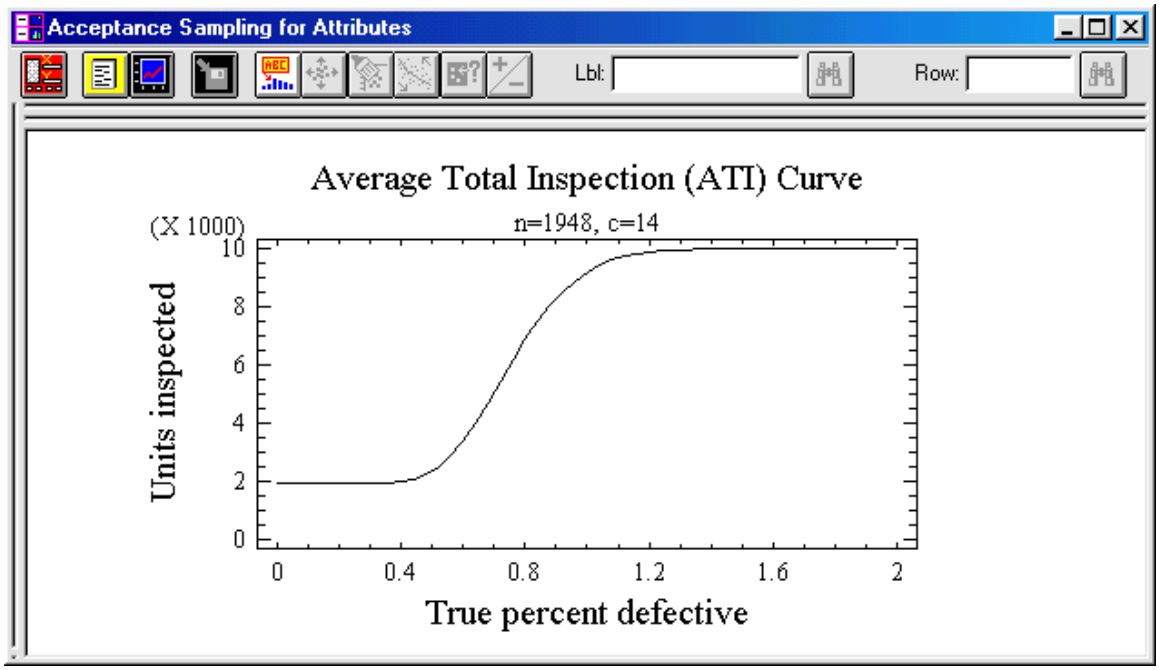


Figure 11-5. ATI Curve

Using the Acceptance Sampling by Variables Analysis

Acceptance sampling by variables has a primary advantage in that you can obtain the same operating-characteristic curve using a smaller sample size than you would using an attributes sampling plan. Therefore, a variables acceptance sampling plan requires fewer samples. Another advantage is that measurement data usually provide more information about the manufacturing process. And, when acceptable quality levels are small, the required sample sizes are usually very large.

MIL STD 414 is a lot-by-lot acceptance sampling sampling plan for variables introduced in 1957. The primary focus of this standard is the acceptable quality level (AQL). Again, Montgomery (1997) provides an informative and in-depth discussion.

To Access the Acceptance Sampling - Variables Analysis

1. Choose SPECIAL... QUALITY CONTROL... ACCEPTANCE SAMPLING... VARIABLES... from the Menu bar to display the Analysis dialog box shown in Figure 11-6.

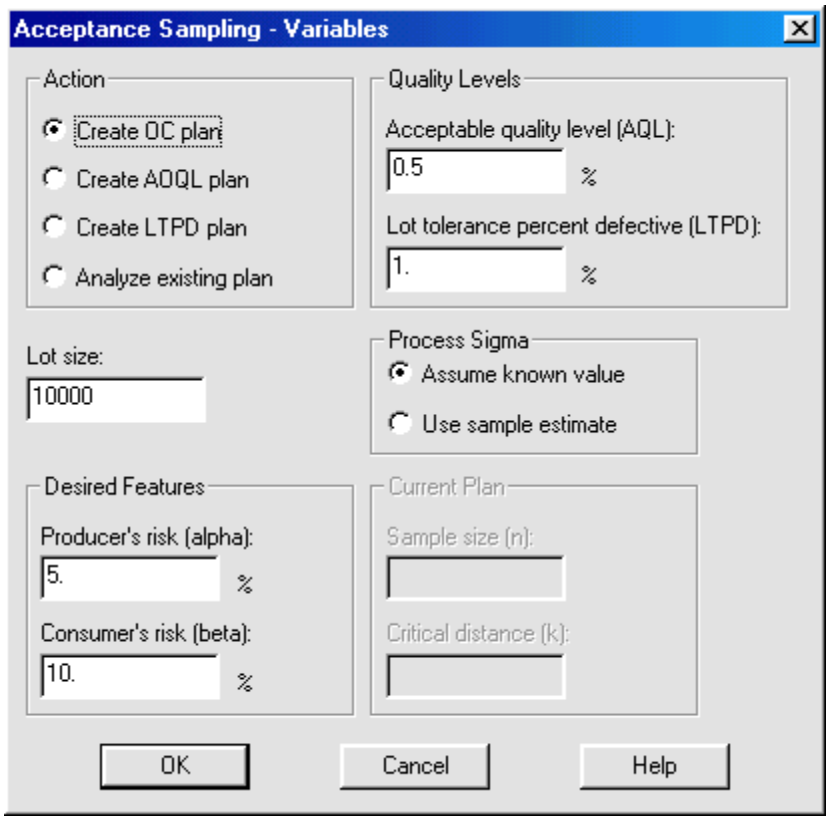


Figure 11-6. Acceptance Sampling Variables Analysis Dialog Box

2. Complete the dialog box and click OK to display the Analysis Summary and the OC Curve in the Analysis window.

Tabular Options

Analysis Summary

The Analysis Summary option creates a summary of the sampling plan created (see Figure 11-7). A summary of the desired features is created, depending on the type of plan you choose. The summary shows the lot size, desired features, generated plan, and the plan attributes.

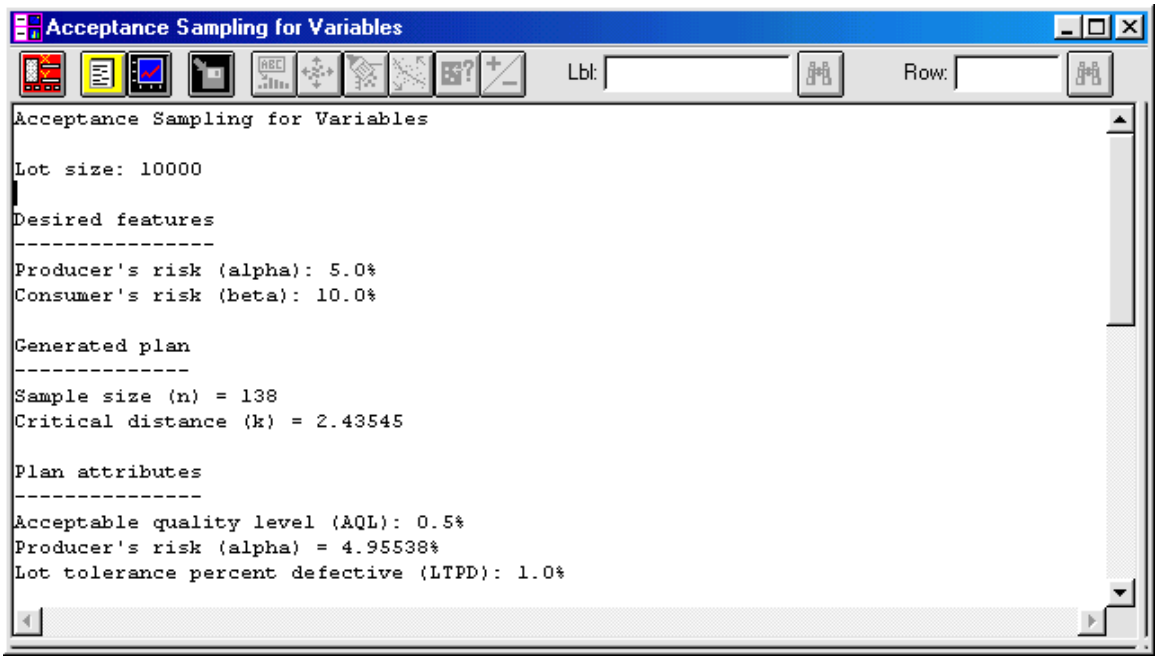


Figure 11-7. Analysis Summary

The Desired Features list includes the producer and consumer risk (alpha and beta), respectively, in percentages. The Generated Plan includes the sample size and the value of the critical distance (k). The values for the Plan Attributes include the Acceptable Quality Level (AQL), the Producer's Risk (alpha), the Lot Tolerance Percent Defective (LTPD), and the Consumer's Risk (beta), all in percentages. Also shown are values for the Average Outgoing Quality Limit (AOQL), and the Average Total Inspection (ATI) at units per lot at the AQL, units per lot at the AOQL, and units per lot at the LTPD.

Graphical Options

OC Curve

The OC (Operating Characteristic) Curve option creates a plot that shows the probability of accepting a lot versus the true percentage of defective items in the lot. You can use the plot to assess the adequacy of the current sampling plan (see Figure 11-8).

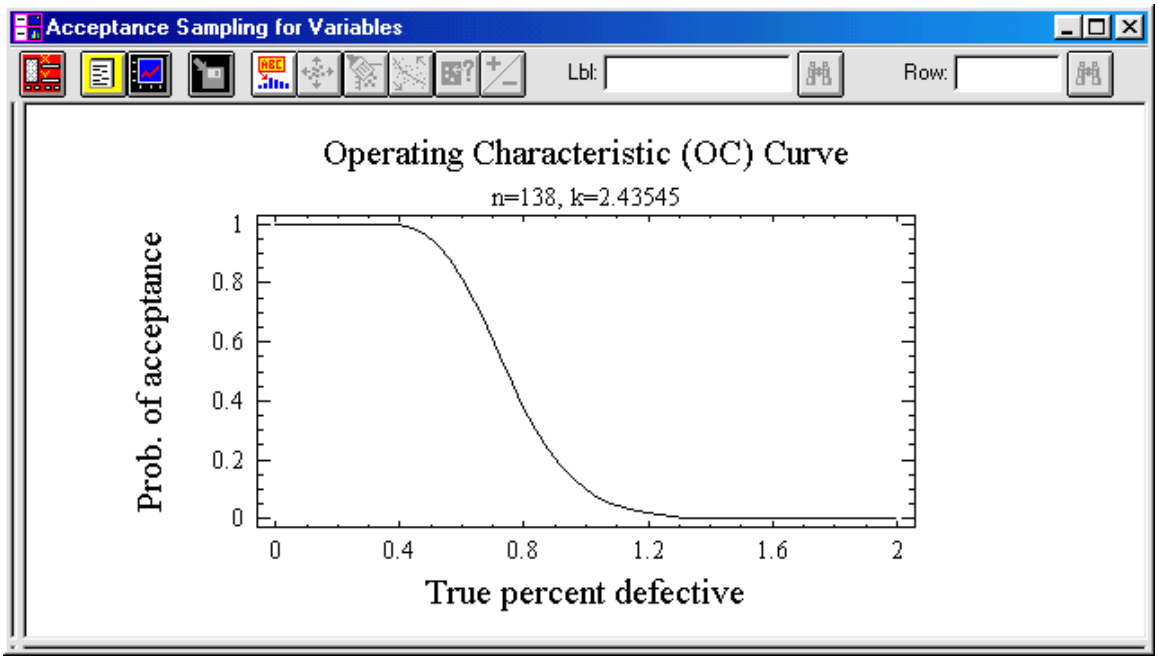


Figure 11-8. OC Curve

AOQ Curve

The AOQ (Average Outgoing Quality) Curve option creates a plot that shows the average percentage of defective items shipped in lots versus the true percentage of defective items in the lot, assuming that all the lots that were rejected by the sampling plan are 100 percent rectified by 100 percent inspection (see Figure 11-9).

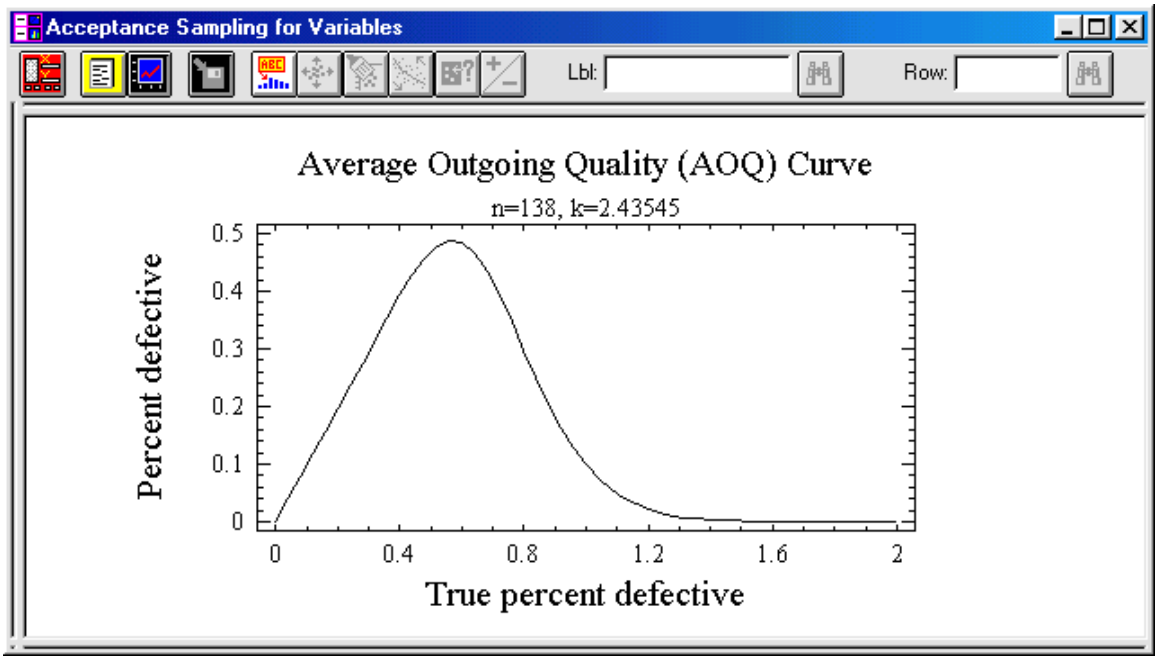


Figure 11-9. AOQ Curve

ATI Curve

The ATI (Average Total Inspection) Curve option creates a plot that shows the average number of units inspected per lot versus the true percentage of defective items in the lot, assuming that all the lots that were rejected by the sampling plan are rectified by 100 percent inspection (see Figure 11-10).

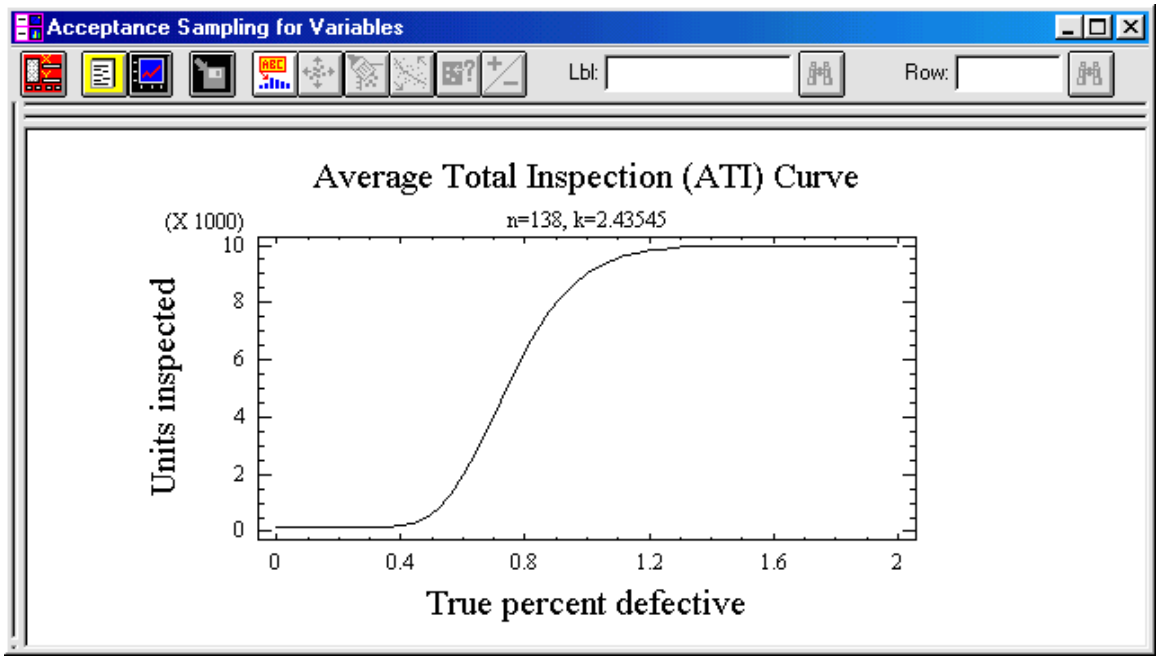


Figure 11-10. ATI Curve

References

Montgomery, D. C. 1997. *Introduction to Statistical Quality Control*, third edition. New York: John Wiley & Sons, Inc.

Chapter 12

USING GAGE LINEARITY AND ACCURACY

Background Information

Chapter 8 described an important type of study often performed to estimate the repeatability and reproducibility of a measurement process. Such studies are concerned entirely with estimating the variability or precision of measurements and are not concerned with potential bias. This chapter considers a different type of study, where the primary goal is to quantify the accuracy of a measurement process.

To quantify the above concepts, suppose that a measurement process when repeated on the same part many times yields measurements which come from a population with mean μ and standard deviation σ. We define the bias of the measurement process as the difference between the mean of that population and the true value being measured, i.e.,

bias = μ - true value

A process is said to be "accurate" if the bias is small. In contrast, precision is directly related to σ, with smaller values of σ being characteristic of "precise" processes. A poor measurement process could be accurate but not precise, or precise but not accurate.

On the other hand, if a measurement is known to have substantial bias, but that bias is consistent across all items being measured, then we may be able to compensate for that bias by adjusting the measured values. Linearity is a term which refers to the difference in the bias throughout the normal operating range of a gage or other measurement instrument. If the bias is consistent, then the linearity will be small.

Gage Linearity and Accuracy

Linearity is the difference in the bias of a gage over its expected operating range. In a typical gage study, repeated measurements are made on a selection of k parts with known characteristics. A linear regression is performed relating the mean bias for each gage to the reference values. From that fit, estimates of the linearity and accuracy of the gage are determined.

To Access Gage Linearity and Accuracy, choose SPECIAL... QUALITY CONTROL...GAGE LINEARITY AND ACCURACY...from the Menu bar to display the Gage Linearity and Accuracy dialog box shown in Figure 12-1.

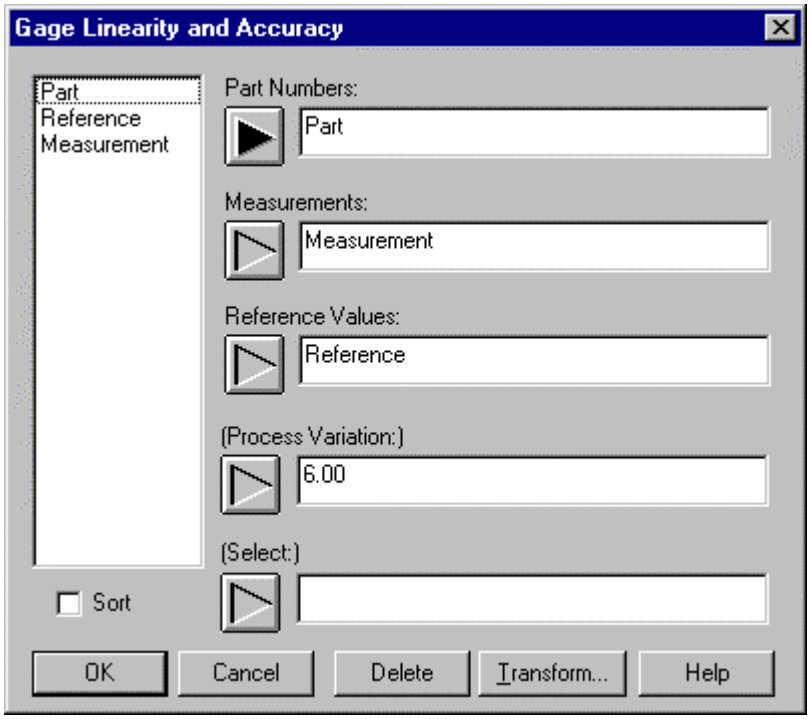


Figure 12-1. Gage Linearity and Accuracy Dialog Box

The data input fields include:

- Part Number - enter the name of the column containing labels or numbers identifying each part in the study.
- Measurements - enter the name of the column containing the measurements.
- References Values - enter the name of the column containing the references values (the true values of the characteristic being measured).
- (Process Variation) - if known, enter 5.15 times the process sigma If not entered, certain statistics will not be calculated.. This value may often be obtained from a previous gage R&R study.

Tabular Options

Analysis Summary

The Analysis Summary pane shows the equation of the fitted model relating bias to the reference values x, a measure of the linearity of the gage, the percentage of linearity, a measure of the correlation between the average measurement for each

part and the reference values (R-squared), the average difference between the mean measurement for each part and its reference value (Bias) and the percentage of bias (see Figure 12-2). The linearity and percent bias are only computed if the process variation is entered.

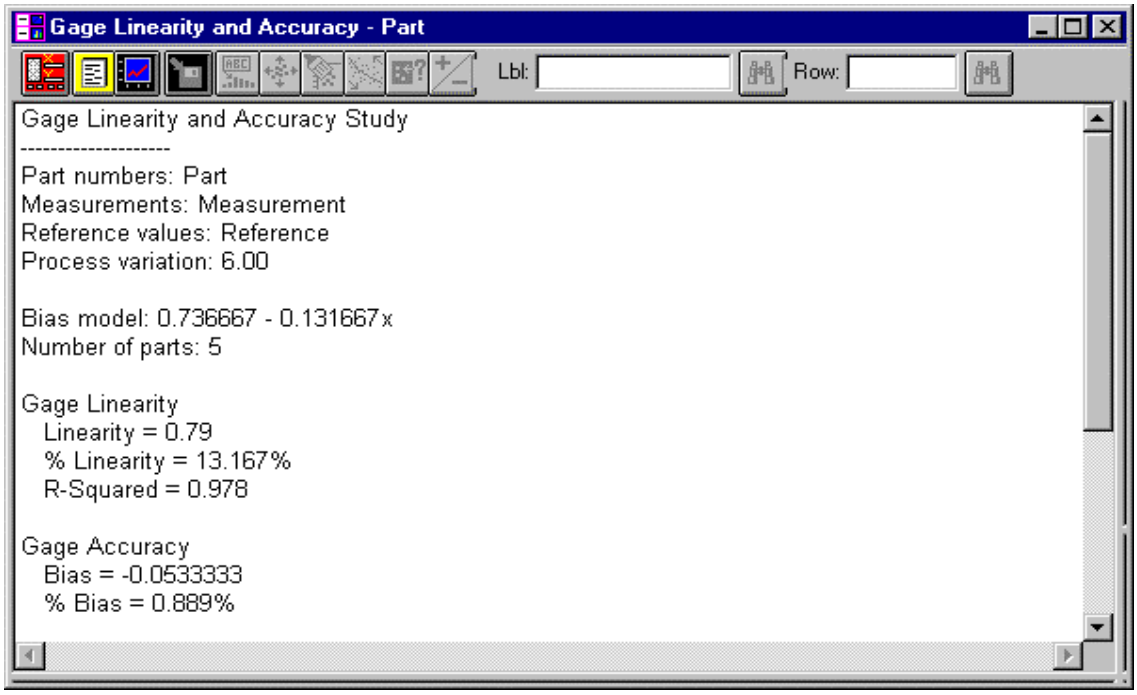


Figure 12-2. Analysis Summary

Analysis Options

Specifies the number of decimal places for displaying all percentages.

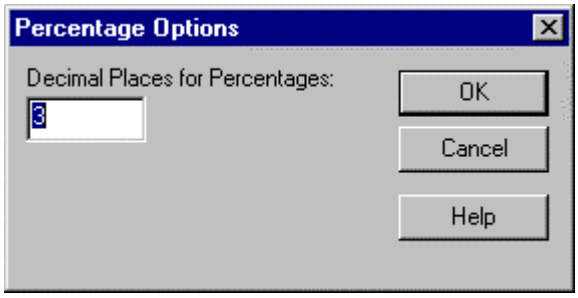


Figure 12-3. Analysis Options Dialog Box

Graphical Options

Fitted Model Plot

The Fitted Model Plot option shows the individual measurements (squares), the average measurement for each gage (circles) , and the fitted regression line fit to the average bias for each of the parts.

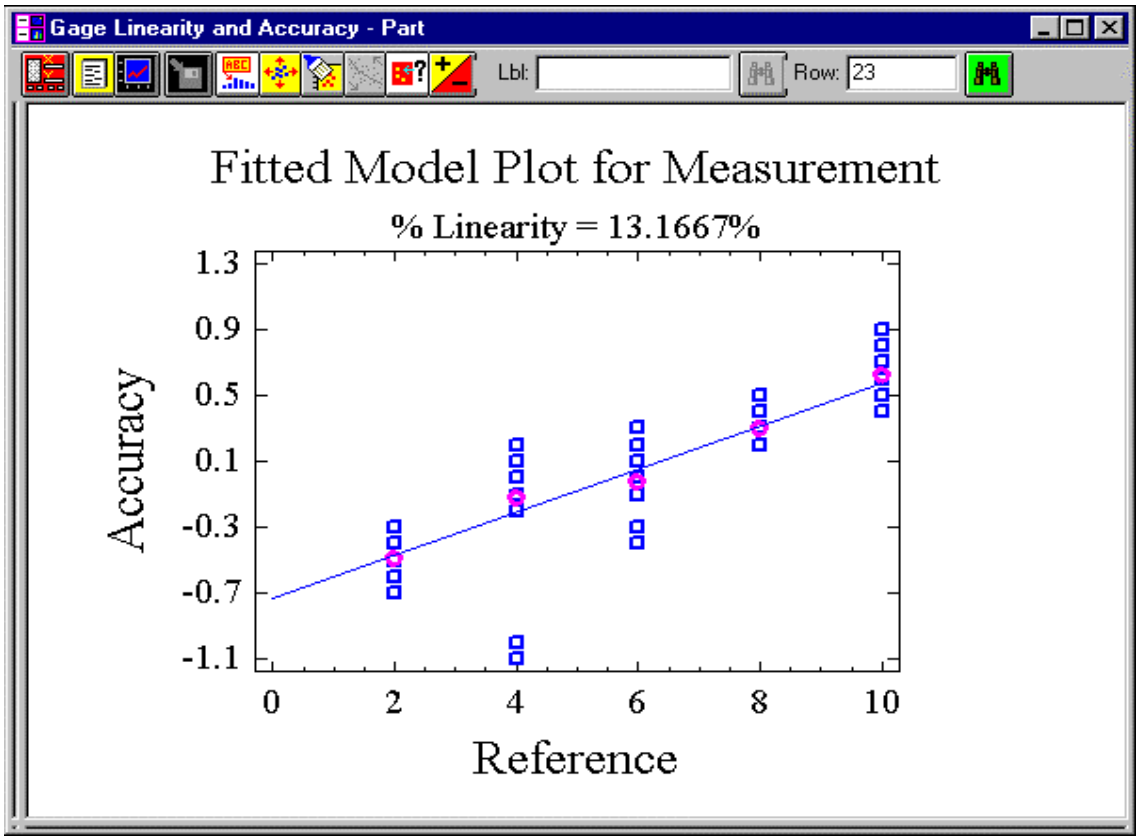


Figure 12-4. Fitted Model Plot

Linearity Plot

The Linearity Plot option shows the bias or average difference between the measurements for each part and their reference values for each gage (circles), and the fitted regression line (see Figure 12-5).

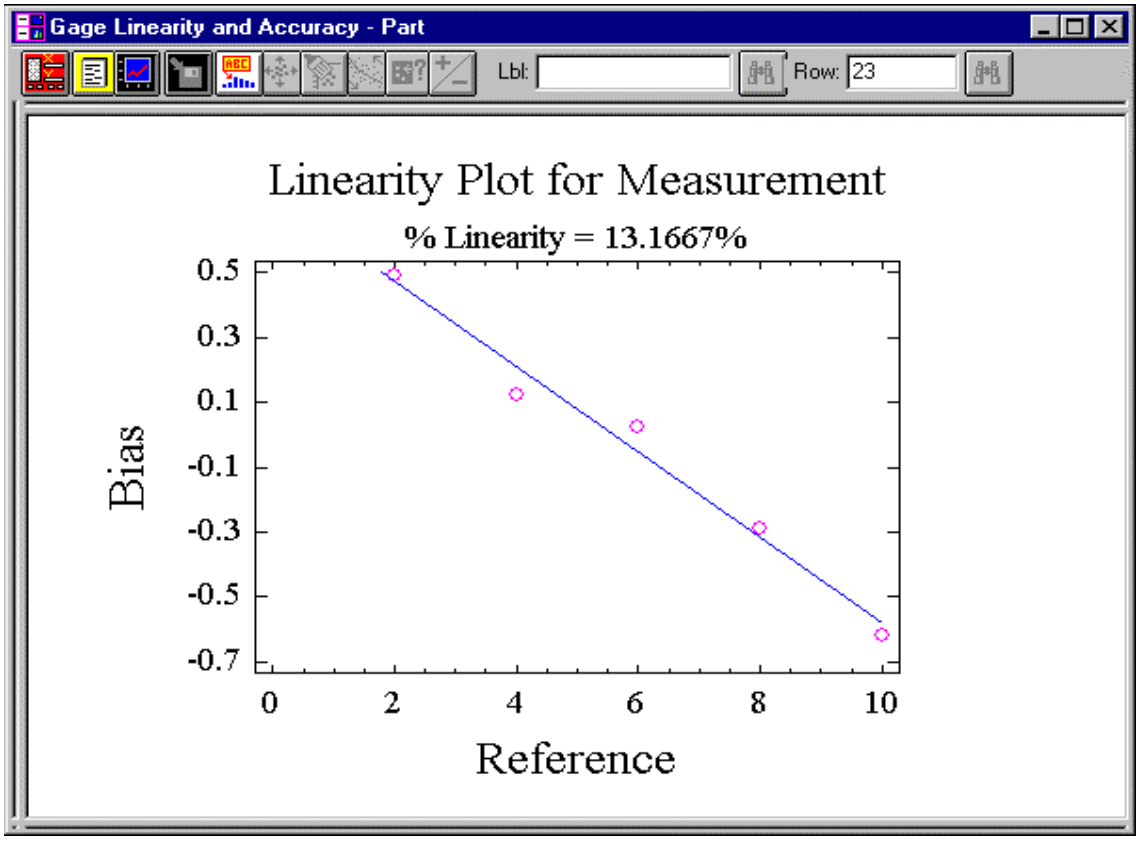


Figure 12-5. Linearity Plot

This is the data actually used to fit the regression line, from which the slope is taken to compute the linearity.

Barchart

The Barchart option shows the estimated linearity and bias as a percent of the product variation (tolerance). It is only plotted if the process variation was entered on the data input dialog box (see Figure 12-6).

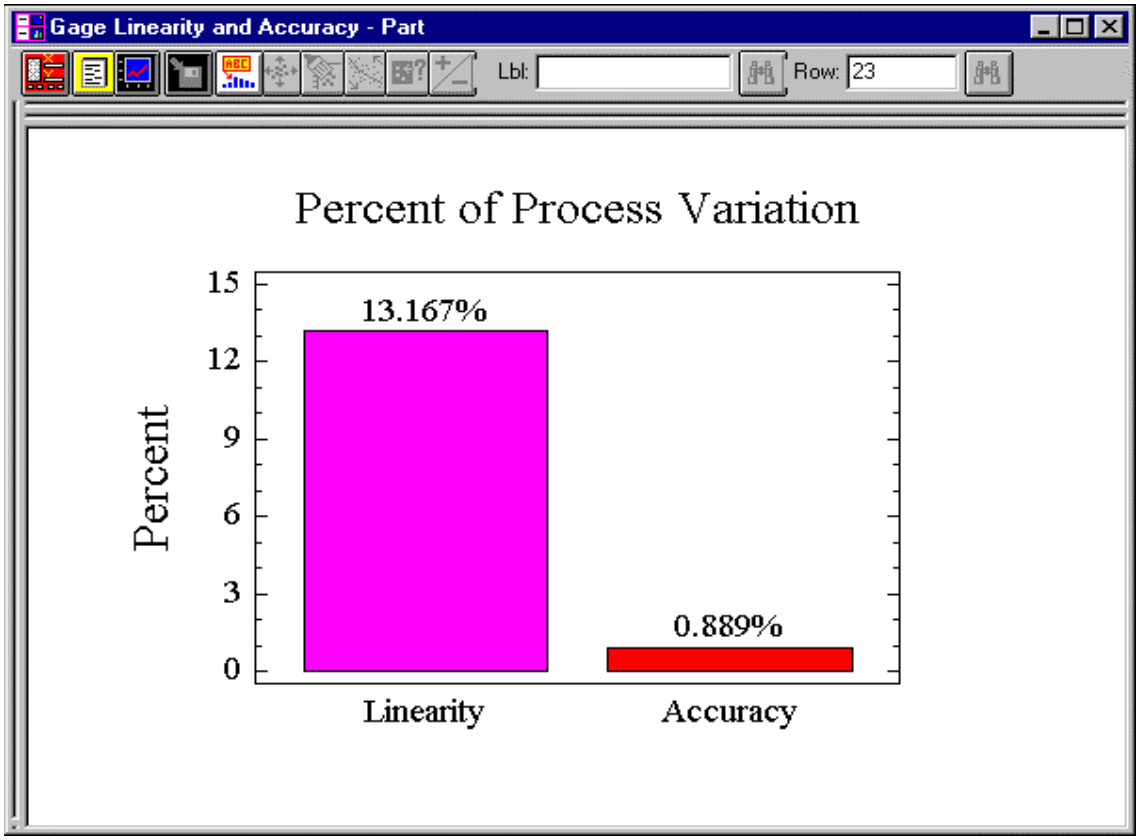


Figure 12-6. Barchart

References

Measurement Systems Analysis Reference Manual. Automotive Industry Action Group (AIAG) 1995. Chrysler/Ford/General Motors Supplier Requirements Task Force

Chapter 13

USING MULTI-VARI CHARTS

Background Information

In complex manufacturing processes, many factors contribute to the variability of the final product. However, not all factors are equally important. A necessary part of any quality improvement effort is separating the important factors from those which contribute little to the overall variability.

A multi-vari chart is a chart designed to display multiple sources of variability in a way which enables the analyst to identify easily which factors are the most important.

Multi-Vari Charts

To Access the Multi-Vari Chart analysis, choose SPECIAL...QUALITY CONTROL...MULTI-VARI CHART... from the Menu bar to display the Multi-Vari Chart dialog box, as shown in Figure 13-1.

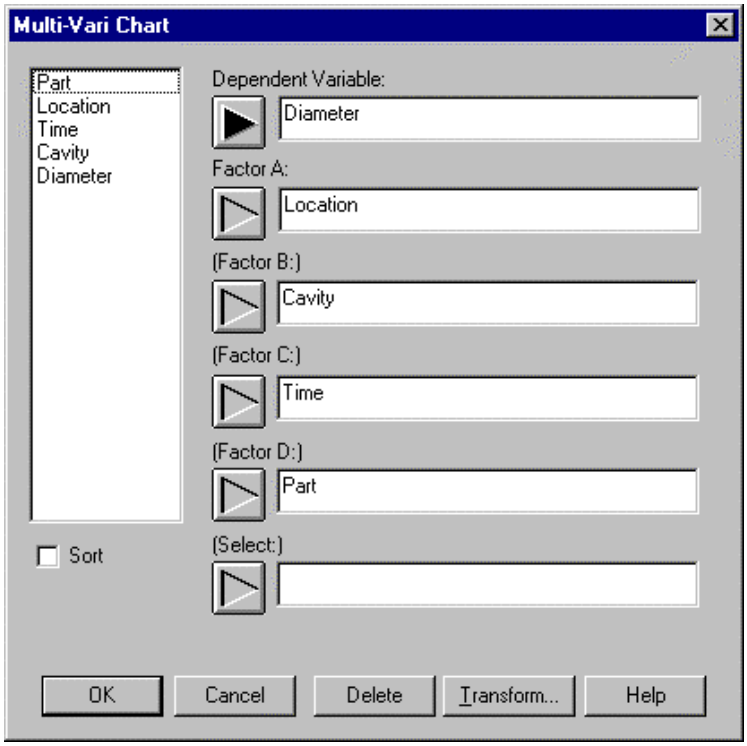


Figure 13-1. Multi-Vari Chart Dialog Box

The fields include:

Dependent Variable - enter the name of the column containing the measurements.

Factor A - enter the name of the column containing levels identifying the first factor. This factor defines the point symbols on the chart.

(Factor B) - enter the name of the column containing levels identifying the second factor, if any. This factor defines how points are grouped on the chart.

(Factor C) - enter the name of the column containing levels identifying the third factor, if any. This factor defines horizontal divisions on the chart.

(Factor D) - enter the name of the column containing levels identifying the fourth factor, if any. This factor defines vertical divisions on the chart.

Only the first two fields are required.

Tabular Options

Analysis Summary
The Analysis Summary option creates a summary of the analysis that includes the name of the dependent variable and the factors, as well as the number of complete cases (see Figure 13-2).

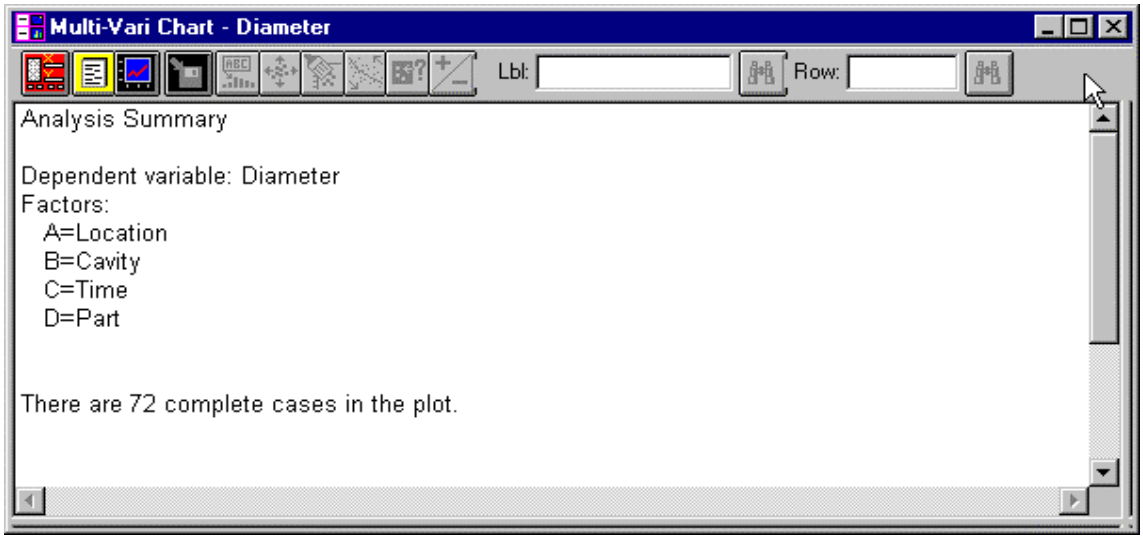


Figure 13-2. Analysis Summary

Graphical Options

Multi-Vari Chart

The Multi-Vari Chart option creates a chart with *a* row of plots displayed for each part, with time increasing along the horizontal axis (see Figure 13-3). Each section of the plot shows the measured diameter at three locations on parts from each of the four cavities. Lines connect the measurements at the 3 locations on each part, the average measurement on each cavity for each part-time combination, the average measurement in each row at each of the 3 times.

Notice that most of the variability is coming from differences between cavities, with location contributing some variability. On the other hand, the effect of time appears to be quite small.

If Part is removed as a factor, the chart takes a slightly different format (see Figure 13-4).

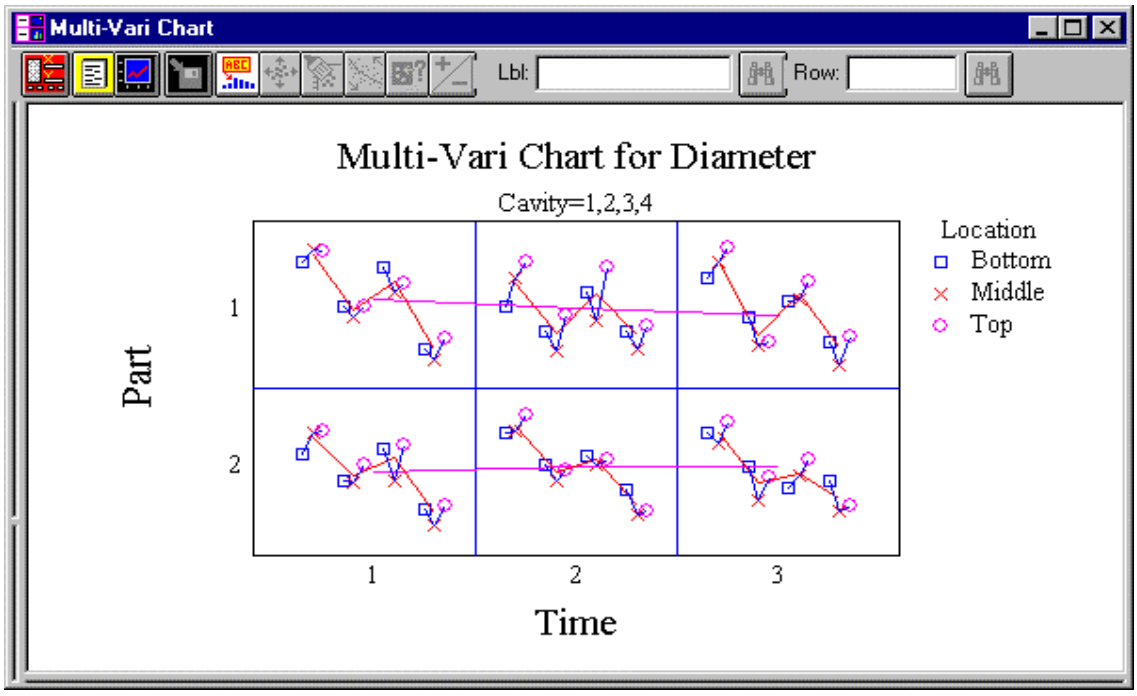


Figure 13.3 Multi-Vari Chart

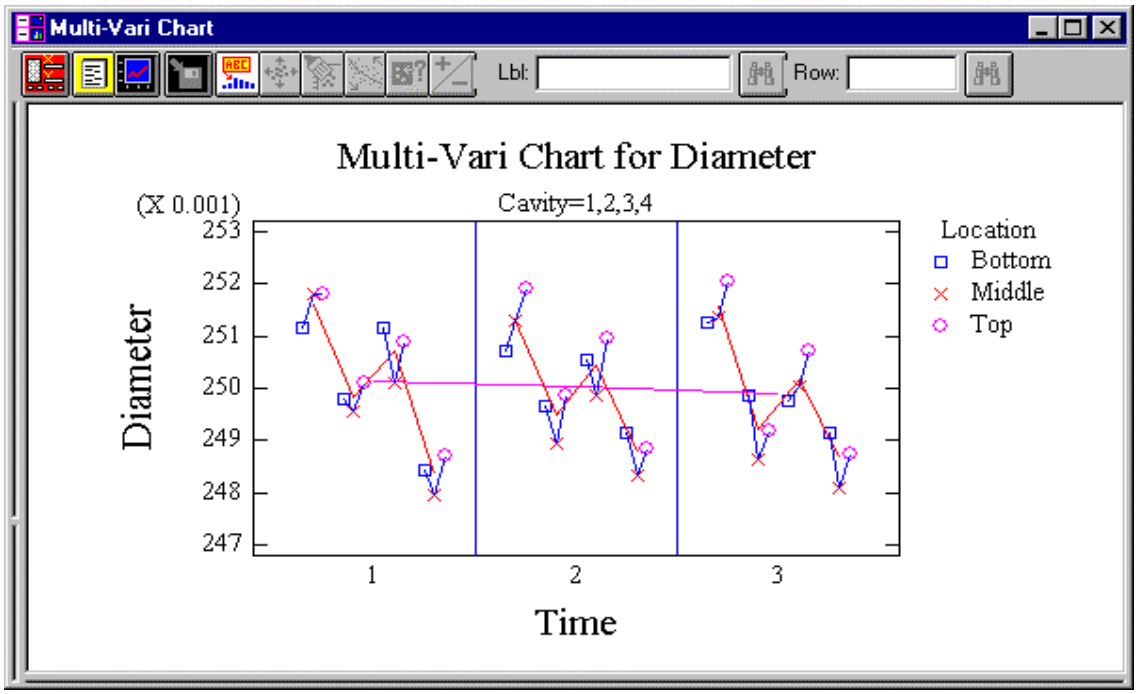


Figure 13.4 Multi-Vari Chart for Three Factors

Each plotted point is now the average of the two parts plotted previously. If more factors are removed, the data is averaged over all levels of the removed factors.

References

Bhote, Keni R. and Bhote, Adi K. (2000). World Classs Quality: Using Design of Experiments to Make It Happen, 2nd edition. New York: American Management Association.

Breyfogle, Forrest W. III (1999). Implementing Six Sigma: Smarter Solutions Using Statistical Methods. New York: John Wiley and Sons.