Process Capability in JMP® 12 – A New Look

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Abstract

JMP 12 includes a new platform for examining the performance of a process in relationship to the specification limits. This paper addresses process capability and the new functionality the Process Capability platform brings to JMP.

The presentation begins with a short introduction to process capability. What is capability analysis and why is it important? The assumptions of the analysis will also be addressed briefly. With this foundation provided, the paper begins the analysis itself the JMP way: graphical evaluation first. This includes a discussion of both goal plots and box plots. Finally, reports provided by the Process Capability platform are discussed.

Introduction

Much attention has been devoted in recent years to quality control. It has been approached under a number of names such as Statistical Quality Control, Statistical Process Control, Total Quality Management, and Six Sigma, to name a few. While the goals of each of these may be stated differently, all have their primary interest in providing a better product to the consumer. In general, we have moved from a world where quality is inspected in (that is, you make the product and then inspect it to be sure that no defective items leave the manufacturing facility) to a world where we consider quality as we develop our process.

Process capability has been defined by many scholars and practitioners. Douglas Montgomery, in his book *Introduction to Statistical Quality Control* states, "Process capability refers to the relationship between the inherent variability in a process compared with the specification for the product." The *NIST Engineering Statistics Handbook* says, "Process capability compares the output of an *in-control* process to the specification limits." Regardless of what definition you choose to use, I believe all would agree that process capability considers both the location and the variability in measuring the ability of a process to meet the specifications of the customer.

The Graphs

There are two primary graphs that are used in JMP to visualize the process capability: the goal plot and the box plot.

The horizontal axis of the goal plot is the difference between the process mean and the target, standardized to the specification (spec).

$$\frac{\bar{Y} - T}{2 * \min(T - LSL, USL - T)}$$

where: USL = upper spec limit
LSL = lower spec limit
T = target

Therefore, positioning left or right indicates a difference between the process mean and the target.

The vertical axis is the standard deviation, standardized to the spec.

$$\frac{SD(Y)}{2 * \min(T - LSL, USL - T)}$$

Positioning high on the graph indicates too much variability in the process. These standardization formulas are adjusted in cases where there is only one spec limit, if there is a missing value for the target, or both. For details, see the JMP Quality and Process Methods book.

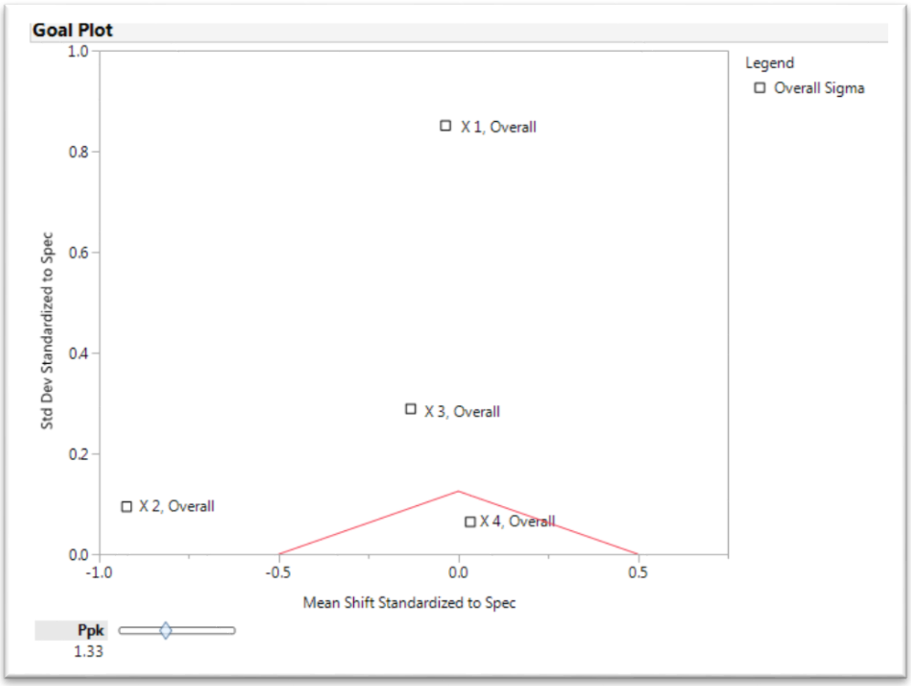


Figure 1

Consider the goal plot shown in Figure 1. Any process that has a Ppk less than the value specified (1.33 in this case) will be inside the red triangle. The cut off value for the red triangle can be changed with the slider at the bottom of the graph. In this case, only X4 is inside the triangle. The X4 process is on target and has acceptable variability. In contrast, X2 has acceptable variability (because it is below the peak of the triangle on the graph), but the process is not on target. The mean for X2 is quite far below the target for the process, which is why the point is to the left of the triangle. Both X1 and X3 are not very far off target, but the variability of these processes is too large, which puts the points above the triangle.

You can also add color to the goal plot, as shown in Figure 2, by selecting Shade Levels from the red triangle menu. The points in the green area are processes that have Ppk greater than twice the specified value. Points in the yellow area indicate processes that have Ppk between the value specified and twice the value specified. Note that the yellow and green areas are both inside the triangle. The points in the red area are processes that have Ppk less than the value specified.

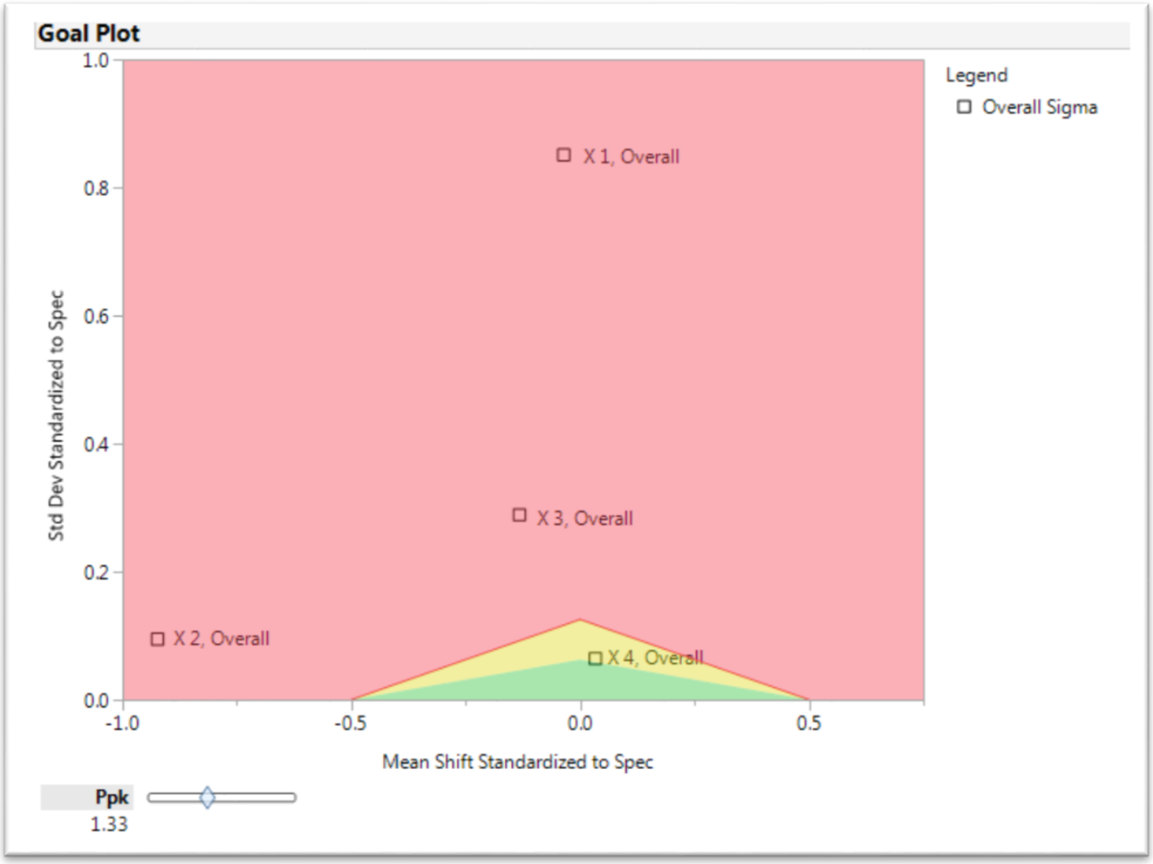


Figure 2

Processes with no target value specified are assumed to have the target at the midpoint of the specification limits. Processes that have only an upper or lower spec limit are displayed as triangles pointing in the direction of the existing spec limit. These points should only be compared to the side of the triangle in the direction they are pointing.

In addition to the goal plot, JMP also provides two types of box plots to visualize the process capability. The capability box plots for the data displayed in the goal plot in Figure 1 appear in Figure 3.

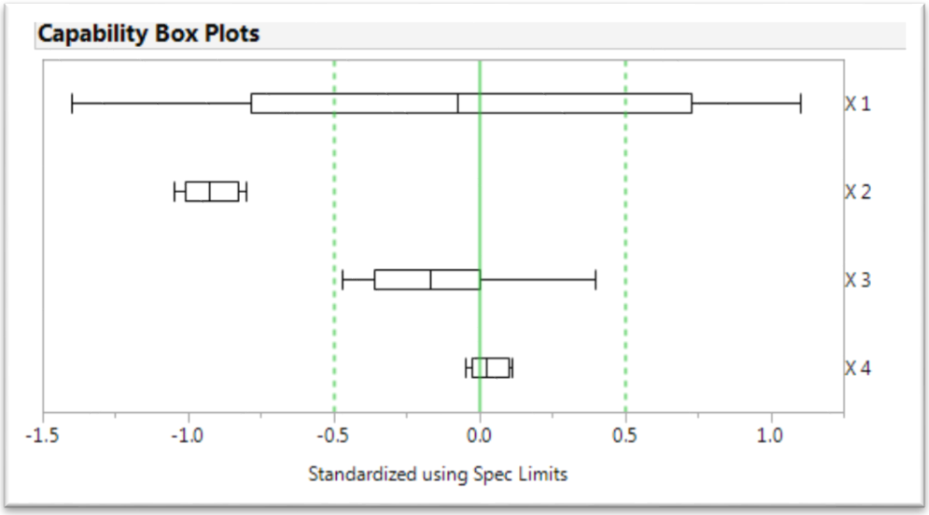


Figure 3

The data are standardized using the target and the spec limits in order to draw these box plots. The standardization formula is:

$$z_i = \frac{x_i - T}{2 * \min(T - LSL, USL - T)}$$

The box plots themselves are outlier boxplots, with the box extending from the 25th percentile to the 75th percentile and the whiskers extending as far as 1.5 times the interquartile range away from the box. A process that is normally distributed and exactly on target will have the median line of the box plot at zero. In addition, if the target is centered between the specification limits, the dashed lines at ±0.5 represent the spec limits.

As was concluded when examining the goal plot, the box plot for X1 shows this process has too much variability. The variability for X2 is very small, but the process is not centered on the target and all measurements would be out of the specification limits. The variability in X3 is not as high as the variability in X1 and all of the measurements are within the specification limits. However, the process is off center, which makes the variability large compared with the distance between the central tendency of the measurements and the lower spec limit. Therefore, the process is not as capable as we would like. Finally, X4 is well centered with low variability, making the process capable of meeting the specifications.

Note that there are several special cases that change how the box plots are drawn:

- If the target is not centered between the specification limits, the values are scaled by twice the smallest difference between the target and the specification limits
- If no target is specified but both the USL and LSL are given, the target is assumed to be centered between the specification limits.
- If the target is specified but there is only one specification limit, the values are scaled by twice the difference between the target and the given specification limit
- If no target is specified and there is only one specification limit, the process mean is used in place of the target value. However, if the mean falls outside of the spec limit, no box plot is created for that process.

Normalized box plots are also an option available from the red triangle menu. These box plots are normalized by subtracting the mean and dividing by the standard deviation. Assuming the normality assumption is met, this results in a standard normal distribution with a mean of zero and a standard deviation of one.

The Indices

Given that process capability is concerned with both the location and the variability in the data, consideration must be given to how the variability, generally referred to as sigma, is estimated.

Overall sigma is estimated using the sample standard deviation, using a formula that will be familiar to many.

$$\hat{\sigma} = s = \sqrt{\frac{\sum(x_i - \overline{x})^2}{n-1}}$$

Assuming the process is stable (in control), this overall sigma estimates the process standard deviation. The overall estimate for sigma is generally referred to as a long-term estimate.

Capability indices can also be based on a within subgroup, or short-term, estimate of the process standard deviation. There are several ways this within subgroup estimate can be calculated. These include:

- the average of the ranges of the subgroups
- the average of the unbiased standard deviations of the subgroups
- the moving range.

JMP also allows you to specify an historical sigma to be used as the within subgroup estimate of variability. If you do not specify a subgroup ID column, a constant subgroup size, or a historical sigma, JMP estimates the within sigma using the moving range of subgroups of size two. With the estimate of variability determined, the capability indices can be calculated.

There are 5 different capability indices available in JMP: Pp, Ppl, Ppu, Ppk, and Cpm. When the indices are calculated using short-term or within subgroup sigma, they are labeled Cp, Cpl, Cpu, Cpk, and Cpm, by default. Looking at the formula for each index will help to determine what issues the index is able to identify.

$$Cp = \frac{USL - LSL}{6\sigma}$$

Cp compares the width of the specification limit to six times the sigma estimate. Therefore, it is able to detect too much variability, but not a problem with location.

$$Cpl = \frac{\mu - LSL}{3\sigma}$$

$$Cpu = \frac{USL - \mu}{3\sigma}$$

Cpl and Cpu look at each side of the process mean independently, computing the difference between the spec limit and the mean for one side. These indices are able to take into account the variability and the location, but for only one side of the process.

$$Cpk = \min(Cpl,\ Cpu)$$

Cpk provides a worst case scenario, taking the minimum of the two single side indices.

$$Cpm = \frac{USL - LSL}{6\sigma\sqrt{1 + (\frac{T - \mu}{\sigma})^2}}$$

Cpm is similar to Cp in that it looks at the width of the spec limits as compared to six times the sigma estimate. However, there is also a penalty for being off target. The larger the distance between the desired target and the actual mean, the larger the penalty.

Note that for a process that is in control and on target Cp = Cpk = Cpm.

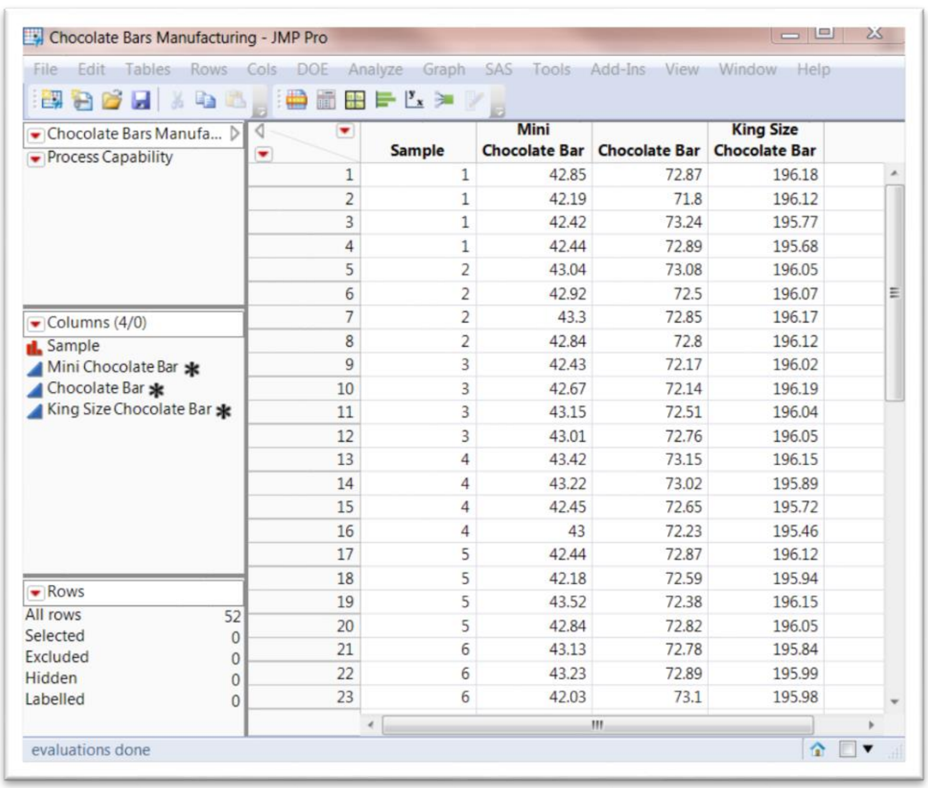
If either of the specification limits is not provided, an index that uses that specification limit is reported as a missing value. If a target value is not provided, the Cpm index is reported as a missing value.

Examples

Chocolate bars anyone?

Suppose a chocolate bar manufacturer makes three different size chocolate bars: king size (198 g), regular size (73 g), and mini (43 g). The manufacturer is interested in the capability of his process to make these different size bars. The smaller the target size for the candy bar, the closer to the stated size the product must be. Therefore, the specification limits for the mini candy bars are tighter than for the regular size bars. The specification limits for the king size candy bar are the loosest at 2 grams either side of the target.

The manufacturer believes that the process is in control and has taken 13 samples of size 4 of each type of candy bar. The data is in the JMP data table Candy Bars Manufacturing.jmp. A portion of the data table is shown in Figure 4.



	Sample	Mini Chocolate Bar	Chocolate Bar	King Size Chocolate Bar
1	1	42.85	72.87	196.18
2	1	42.19	71.8	196.12
3	1	42.42	73.24	195.77
4	1	42.44	72.89	195.68
5	2	43.04	73.08	196.05
6	2	42.92	72.5	196.07
7	2	43.3	72.85	196.17
8	2	42.84	72.8	196.12
9	3	42.43	72.17	196.02
10	3	42.67	72.14	196.19
11	3	43.15	72.51	196.04
12	3	43.01	72.76	196.05
13	4	43.42	73.15	196.15
14	4	43.22	73.02	195.89
15	4	42.45	72.65	195.72
16	4	43	72.23	195.46
17	5	42.44	72.87	196.12
18	5	42.18	72.59	195.94
19	5	43.52	72.38	196.15
20	5	42.84	72.82	196.05
21	6	43.13	72.78	195.84
22	6	43.23	72.89	195.99
23	6	42.03	73.1	195.98

Figure 4

Each of the process columns in this data table has a spec limits column property, which provides the target and spec limit for JMP.

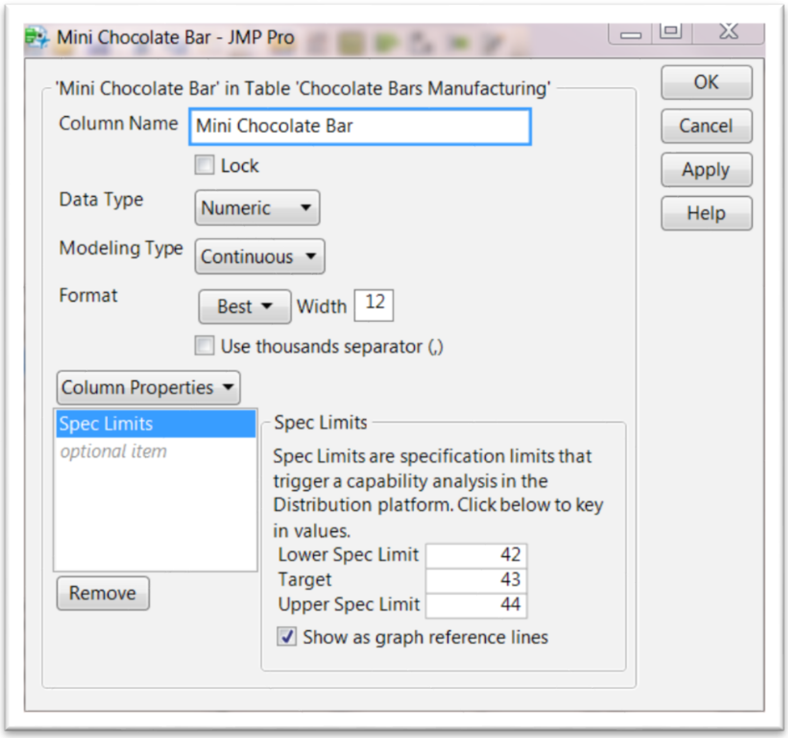


Figure 5

To do a capability analysis on these three processes:

1. Select Analyze → Quality and Process → Process Capability
2. Select the three process columns and then click on the Y, Process button
3. To assign the subgroup ID variable, click on the triangle next to Process Subgrouping to reveal that panel
4. Select Sample in the columns list and the three process variables in the process variables list
5. Click on Nest Subgroup ID Column

The dialog box should now appear as shown in Figure 6.

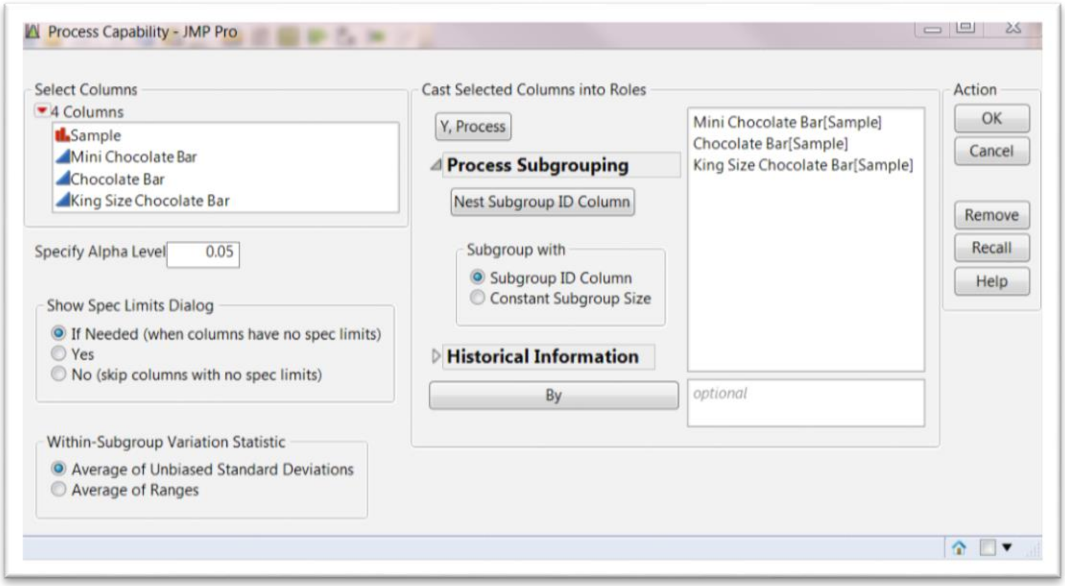


Figure 6

Notice that you can also specify historical information and a By variable in this dialog. Other options include the ability to specify the within subgroup variation statistic, an alpha level, and provide direction about what should happen if the process columns do not have spec limits.

After clicking OK, the goal plot and capability box plots are shown. The Goal Plot red triangle menu will allow you to show the within sigma points, add shading to the plot as discussed previously, label the overall sigma rate, and add a defect rate contour. After turning on the labels and shading, the goal plot should appear as in Figure 7.

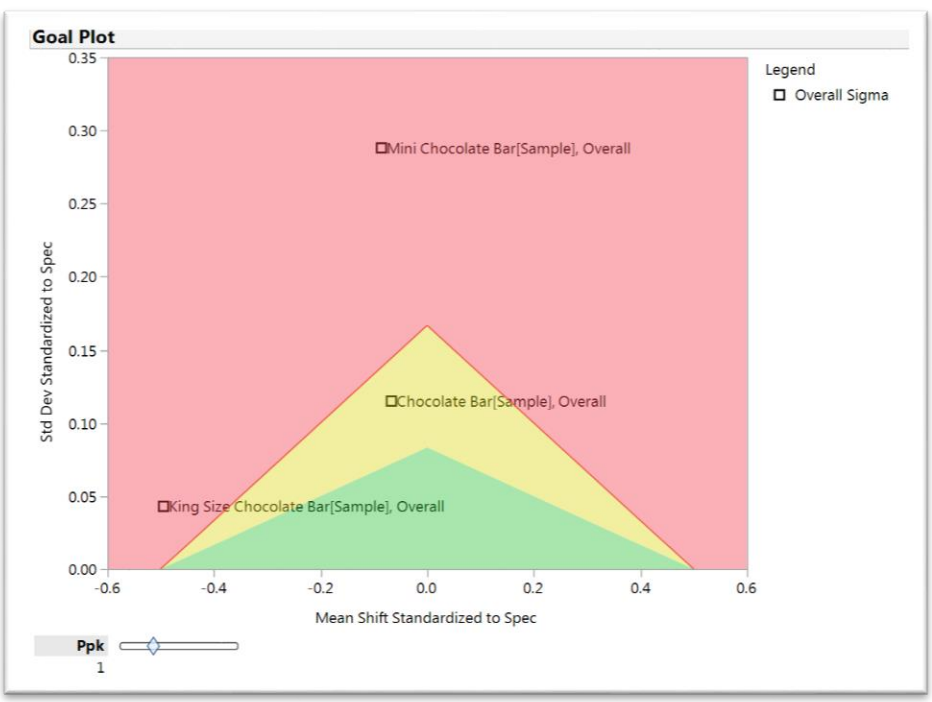


Figure 7

The points on the goal plot are based on the overall sigma. As this data has rational subgroups, it may be interesting to consider the within sigma points. With those points added to the goal plot, the plot appears as in Figure 8.

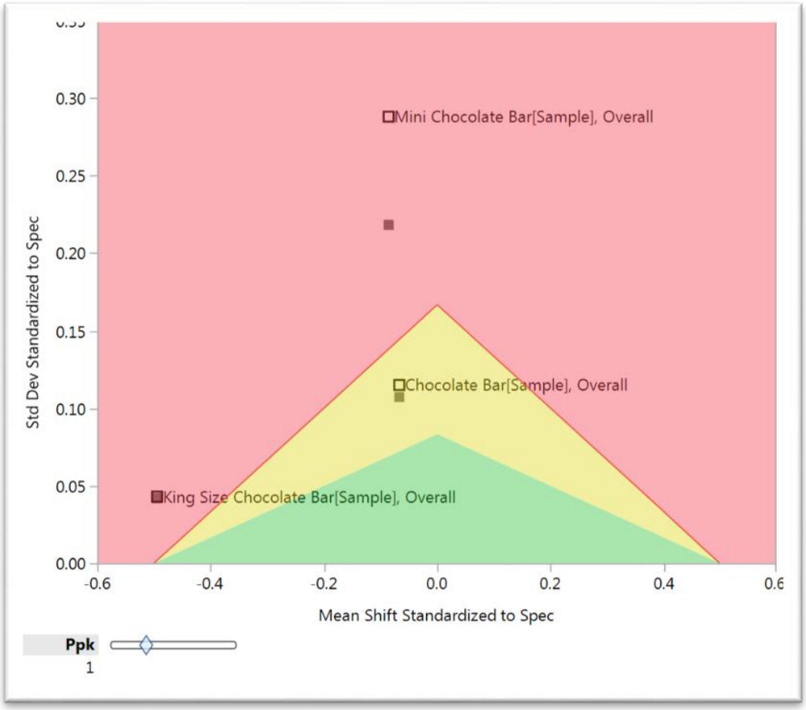


Figure 8

The points for the regular and king size bars are similar using both estimates of sigma. However, the two points for the mini bars are quite far apart. The within group estimate of sigma appears to be much smaller than the overall sigma. This may be an indication of a problem with the data or the process.

Examining the capability box plots, shown in figure 9, the mini chocolate bars have very wide range and some outliers. The regular size bars also have some outliers, but the spread of the data is much smaller than the mini bars. Finally, the king size bars have the narrowest spread, but the center of the data is much lower than the target.

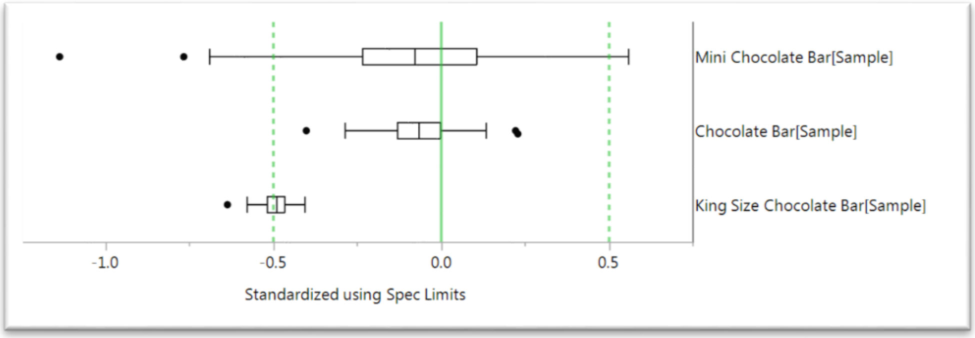


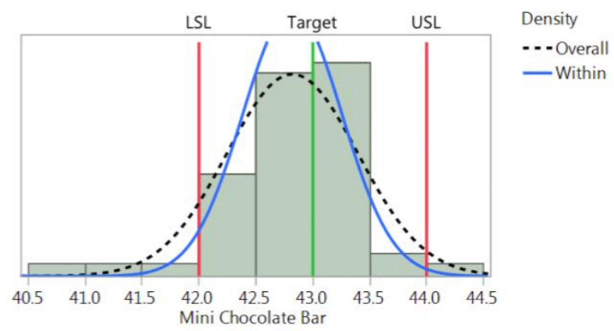
Figure 9

Having visually examined the data, with the goal plot and box plots, the next step in data exploration might be to look at one additional graphical representation of the data, a histogram, along with some descriptive statistics. These are readily available by selecting the Individual Detail Reports option from the red triangle menu. This report, for the mini chocolate bars, is shown as Figure 10 below.

Mini Chocolate Bar[Sample] Capability

Grouped by subgroup ID: Sample

Histogram



Process Summary

LSL	42
Target	43
USL	44
N	52
N Subgroups	13
Mean	42.82615
Within Sigma	0.437305
Overall Sigma	0.576807

Within sigma estimated by average of unbiased standard deviations.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	0.630	0.459	0.800
Cpl	0.630	0.458	0.798
Cpu	0.895	0.670	1.117
Cp	0.762	0.588	0.936
Cpm	0.708	0.574	0.843

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	0.477	0.348	0.607
Ppl	0.477	0.347	0.606
Ppu	0.678	0.518	0.837
Pp	0.578	0.466	0.690
Cpm	0.553	0.452	0.665

Nonconformance

Portion	Observed %	Expected Within %	Expected Overall %
Below LSL	5.7692	2.9433	7.6031
Above USL	1.9231	0.3634	2.0922
Total Outside	7.6923	3.3067	9.6952

Figure 10

Included in the individual detail report are a histogram, process summary, capability indices, and nonconformance information. The histogram shows the distribution of the data, with the spec limits. In addition, two normal curves are displayed, one drawn using the overall estimate of sigma and the other drawn using the within groups estimate. Both of the curves are based on the sample mean, therefore they have the same center. Of primary importance in this case is that the two curves are not very close together, indicating a nontrivial difference between the two sigma estimates. You can see the estimates of sigma in the Process Summary table. Examining the reports for the other sizes of candy bar, you will note that the two curves for each histogram are close together.

Based on the information gathered so far, a closer look at the data may be warranted to confirm that the process is in control and that there are no anomalies in the data. One way to examine the data further might be with a XBar control chart. To generate an XBar chart:

1. Select Analyze → Quality and Process → Control Chart Builder
2. Drag Mini Chocolate Bar to the Y drop zone on the left side of the graph area
3. Drag Sample to the drop zone at the bottom of the graph area

Examine the control chart.

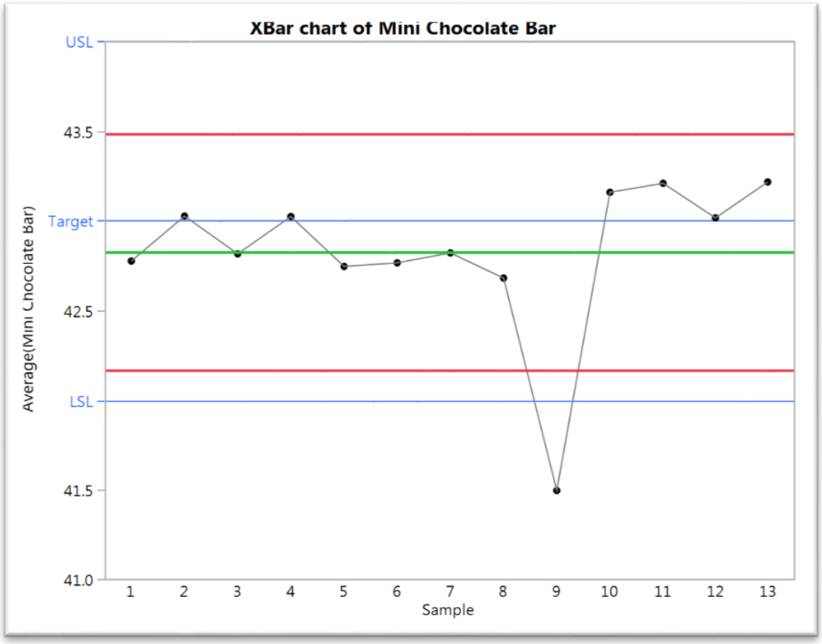


Figure 11

There is clearly one subgroup that is both outside of the control limits and the spec limits. Suppose, after investigating, you determine that the sample in question was taken when there was a known problem on the production line. The problem was subsequently fixed before sample 10 was taken. As this is a known cause, we can comfortably exclude the data from the control chart and the capability analysis. To do so:

1. Click on the point for sample 9 in the control chart. This selects the 4 rows for that sample in the data table.
2. Select Rows → Hide and Exclude.

Re-examining the control chart (as shown in Figure 12) shows that the process now appears to be in control.

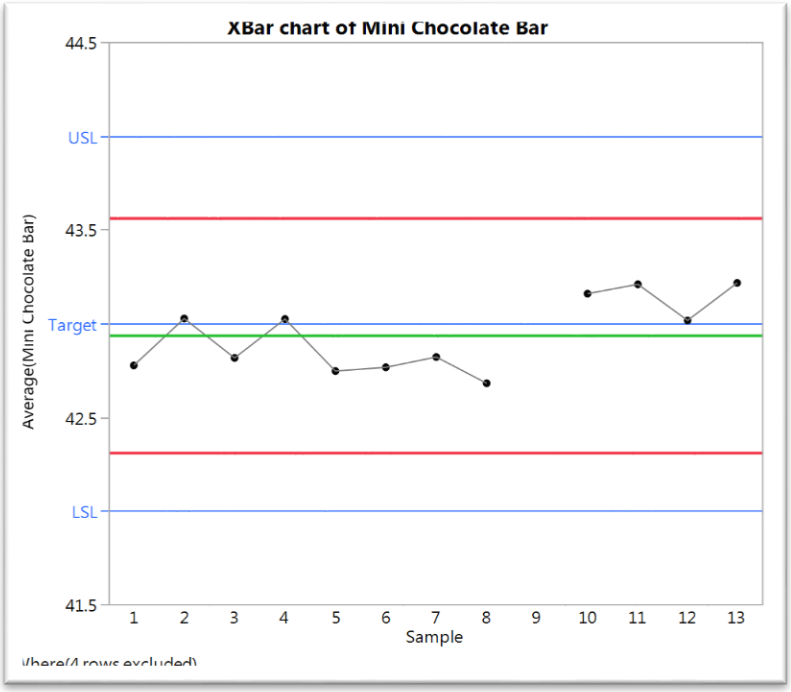


Figure 12

If the auto recalc option has been turned on for the Process Capability platform or for this analysis, those results will automatically update with the exclusion of the data rows. If the auto recalc option is not on, you can rerun the analysis after excluding the rows. Examining the new output, you can see that the within and overall estimates of sigma for the mini bars are much closer than before, making the normal curves also very close. You can also see this in the Goal Plot, shown in figure 13, where the points are virtually on top of one another for the mini bars.

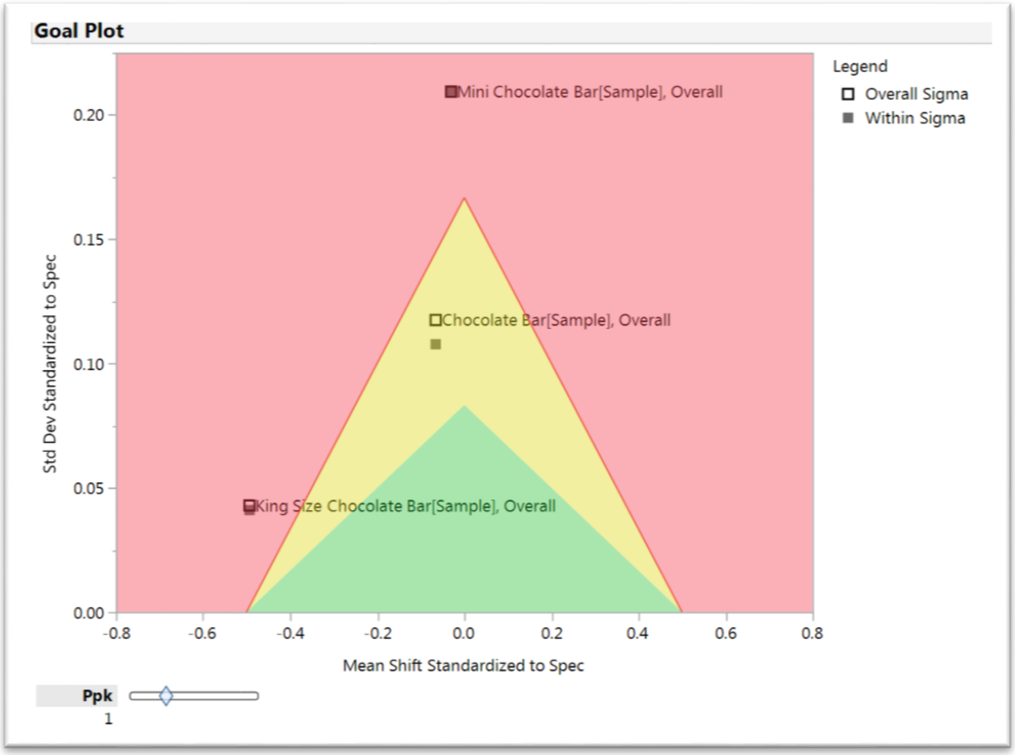


Figure 13

Initial conclusions that might be drawn from the goal plot are:

- King size bars exhibit low variability, but the mean is off target on the low side.
- Regular size bars fall within the yellow area of the triangle, indicating Ppk is greater than 1, but less than 2.
- Mini bars have too much variability for the process to be considered capable, but the process appears to be close to on target.

The Within Sigma Capability Summary Report will give us a compact look at the capability indices for the three products. To view this, select Summary Reports → Within Sigma Summary Report from the Process Capability red triangle menu.

Within Sigma Capability Summary Report

Process	LSL	Target	USL	Mean	Std Dev	Cpk
Mini Chocolate Bar[Sample]	42	43	44	42.93688	0.420056	0.743
Chocolate Bar[Sample]	71.5	73	74.5	72.79854	0.324042	1.336
King Size Chocolate Bar[Sample]	196	198	200	196.0208	0.16513	0.042

Figure 14

Based on the Cpk statistics shown in figure 14, the mini chocolate and king size chocolate bar processes are not capable. Corrective action will be necessary if the product is to meet the specifications. To get a sense of the impact this may have, look at the values provided in the same table on the expected percent of product outside of the spec limits.

Process	Mean	Std Dev	Expected % Outside	Expected % Below LSL	Expected % Above USL
Mini Chocolate Bar[Sample]	42.93688	0.420056	1.8550	1.2862	0.5688
Chocolate Bar[Sample]	72.79854	0.324042	0.0031	0.0031	0.0000
King Size Chocolate Bar[Sample]	196.0208	0.16513	44.9801	44.9801	0.0000

Figure 15

Although the variability for the King Size bars is the smallest, almost 45% of the product is expected to be below the lower specification limit. While the process is capable in terms of the variability, our process is producing king size bars that are too small. As noted earlier, the location is a problem for this process.

On the road again – tire tread data

The chocolate bar example included three process variables all of which had an upper and lower specification limit and a target in the center of the two limits. This is not always the case. The following situations are also possible:

- An upper and lower spec limit with an off center target
- An upper and lower spec limit, but no target
- A target with either an upper or a lower spec limit
- An upper or lower spec limit, but no target

The Process Capability platform is capable of handling each of these situations.

The Tire Treads.jmp data table contains two columns of data that are measurements of tire tread depth. The two columns contain the same data, but for illustration purposes, the spec limits for the two columns are different as shown in Table 1.

	Tire Tread 1	**Tire Tread 2**
LSL	0.31	0.31
Target	0.34	**.**
USL	**.**	0.36

Table 1

Notice that both columns have the same lower spec limit. However, the first column has no upper spec limit given and the second column has no value for the target.

Begin by running the script that has been saved to the data table. The Individual Detail Reports have been turned on with the script. First examine the histograms and process summary table for each of the columns.

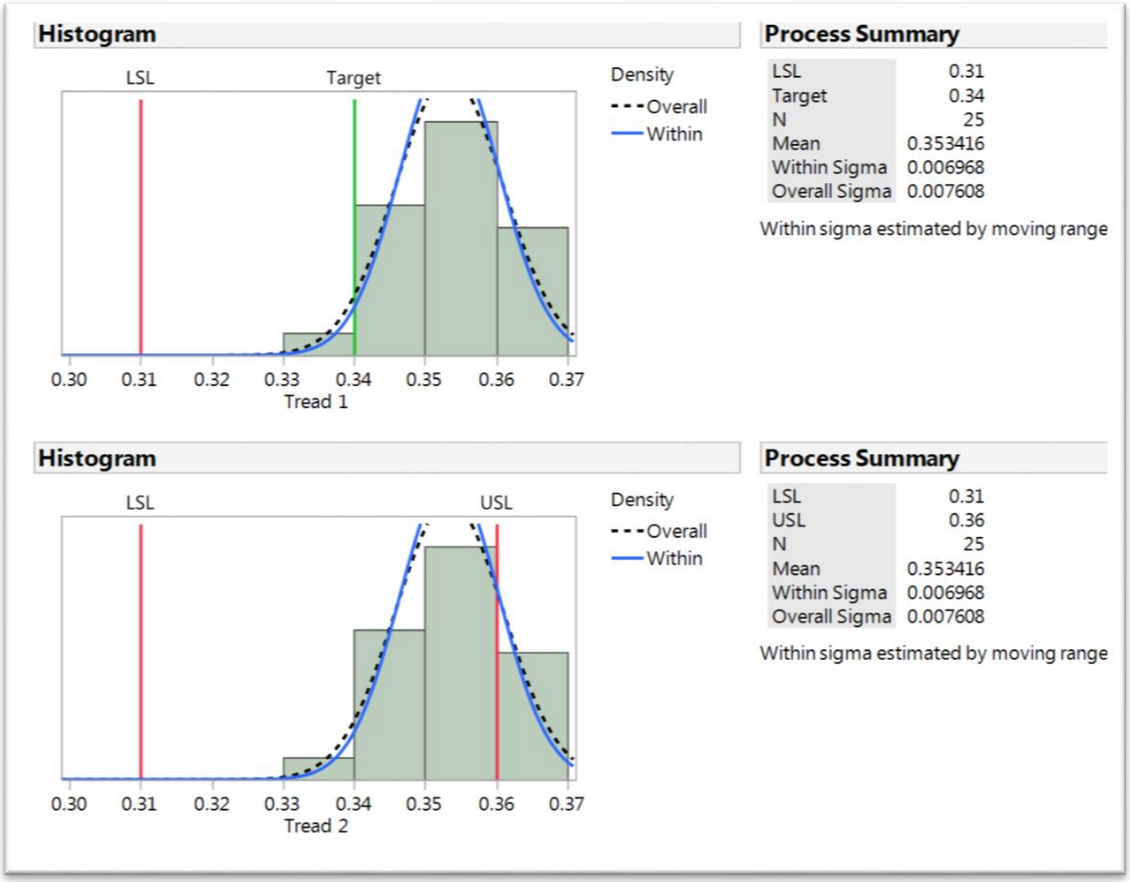


Figure 16

As was mentioned earlier, the data in the two columns is the same for illustrative purposes. This is evident in the Process Summary table, as they both show the same mean and sigma. In this case, no process subgroup variable was available, so the within sigma is estimated using a moving range of subgroups of size 2.

Examining the histograms, you can see that given the Target of 0.34 for Tread 1, the process appears to be off target. However, because there is not an upper spec limit, there are no out of spec values. By contrast, Tread 2 has an upper spec limit, so there are out of spec values.

It may be interesting to examine the data points that are outside of the specification limits. One way to do so is by highlighting those points in the data table. From the red triangle menu, select Out of Spec Values → Color Out of Spec Values. Looking at the data table, you can see that the cells with values above the USL for Tire Tread 2 are highlighted in blue. If there were cells with values below the LSL they would be highlighted in red.

Examine the sigma capability reports and nonconformance report for Tread 1, as shown in Figure 17.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	2.077	1.326	2.825
Cpl	2.077	1.326	2.825
Cpm	0.661	.	.

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	1.902	1.350	2.451
Ppl	1.902	1.350	2.451
Cpm	0.648	.	.

Nonconformance

Portion	Observed %	Expected Within %	Expected Overall %
Below LSL	0.0000	0.0000	0.0000
Total Outside	0.0000	0.0000	0.0000

Figure 17

With no upper spec limit, Ppu cannot be calculated. Therefore Ppl and Ppk are equal. Looking at these capability indices and the expected nonconformance rate of 0% would indicate this is a capable process. However, none of these measures considers the Target value. The Cpm contains a penalty for being off target. Therefore, it is much lower than 1, indicating it is not capable of meeting the expectations of the customer.

Examine the sigma capability and nonconformance tables for Tread 2, as shown in Figure 18.

Within Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Cpk	0.315	0.142	0.488
Cpl	2.077	1.326	2.825
Cpu	0.315	0.140	0.484
Cp	1.196	0.771	1.621

Overall Sigma Capability

Index	Estimate	Lower 95%	Upper 95%
Ppk	0.288	0.134	0.443
Ppl	1.902	1.350	2.451
Ppu	0.288	0.132	0.440
Pp	1.095	0.787	1.403

Nonconformance

Portion	Observed %	Expected Within %	Expected Overall %
Below LSL	0.0000	0.0000	0.0000
Above USL	24.0000	17.2356	19.3408
Total Outside	24.0000	17.2356	19.3408

Figure 18

For Tread 2, it is more obvious that the process is not capable based on the Cpk statistic and expected nonconformance percentages.

Conclusion

Process capability is traditionally intended to detect problems with location and variability for an in control, normally distributed process. In JMP® 12, the new Process Capability platform is designed to assess process capability both visually and statistically with a combination of graphs and tables. Process capability for in control, but non-normally distributed processes can still be addressed with the JMP Distribution platform. JMP® 13 is expected to include process capability analysis on non-normal data in this new platform.

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