PROCESS CAPABILITY OF THE ZELLWEGER 900-AUTOMATIC WITH DUAL COLOR HEADS: A COMPARISON OF 1994 AND 1995 RESULTS

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Abstract

Process capability analysis was performed on newly purchased Zellweger model 900-Automatic High Volume Instruments with dual color heads in 1994 and 1995 using the same methodology for the fiber properties of micronaire, strength, length and uniformity. The results from the two years were compared. Improvements in the C_p and C_{pk} indices and in the ratio of the C_{pk} index to the C_p index were seen despite little or no decreases in measurement variability. This is due to a decrease in the variability between instruments.

Introduction

Process capability is an accepted methodology for estimating the variability of a process and for determining if the process can generate product within specified tolerances. Process capability is defined as six times the process sigma (F), or standard deviation. In addition, process capability allows for calculating indices that categorize the process as unacceptable, marginal or acceptable. The C_p index is calculated by dividing the tolerance range by the process capability:

$$|UTL - LTL| / 6\sigma$$

where UTL is the upper tolerance limit and LTL is the lower tolerance limit. The capability ratio, or C_p index, indicates if the process can generate product within specifications when perfectly centered. The performance ratio, or C_{pk} index, is calculated by taking the absolute value of the difference between the process mean and the nearest tolerance limit and dividing this value by three times the process sigma:

$$|Mean - NTL| / 3\sigma$$

where NTL is the nearest tolerance limit. The C_{pk} index determines if the process can generate product within specifications when it is centered at a level that can normally be expected during production.

The USDA, AMS, Cotton Division conducts process capability studies (PCS) on all new High Volume Instruments (HVI) to determine the variability of cotton fiber testing and the capability of each instrument to generate fiber property measurements within specifications. The Zellweger Uster HVI model 900-Automatic with dual color heads (900-U) was first manufactured in 1994 and purchased by USDA that year. A PCS was conducted on 30 instruments at the time of delivery. Twenty additional units of this model were again purchased in 1995. Again a process capability study was conducted on these instruments. The 1994 process capability results were compared to the 1995 results to determine if any significant or appreciable changes had occurred in the results of the two years.

Materials and Methods

The Cotton Division has used standardized methods for collecting and analyzing PCS data since the first studies were conducted in 1991. These methods are detailed by Lewicki, et al (1995). Analysis includes determining if the instruments are operating in a state of statistical control through the use of X-Bar and Range control charts, calculating process standard deviations and process capabilities and computing C_p and C_{pk} indices. An additional method of data analysis was employed with the 1994 and 1995 900-U data. The ratio of the C_{pk} indices to the C_p indices were calculated and these values averaged for all instruments tested in each year. Interpretation of the indices and the ratios is as follows:

C_p and C_{pk} Indices
< 1.00......................Unacceptable
≥ 1.00 but ≤ 1.33.....Marginal
> 1.33......................Acceptable

C_{pk}/C_p Ratios
< 0.75......................Unacceptable
≥ 0.75 but ≤ 0.90.....Marginal
>0.90.......................Acceptable

When comparing process capabilities, C_p indices and C_{pk} indices, a 15 percent rule was used; i.e. if the percent change from one year to the next was greater than $\pm$ 0.15, this was regarded as an appreciable change.

Results and Discussion

Control Charts

Figures 1 through 4 display X-Bar control charts for micronaire, strength, length and uniformity, respectively. An instrument's X-Bar chart was determined to be in a state of statistical control for a particular fiber property if not more than one point on the chart violated any of the following four decision rules:

1. Any point beyond the three F control limits
2. Any two of three consecutive points beyond the two F limits

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3. Any four of five consecutive points beyond the one F limits

4. Any eight consecutive points on one side of the center line

Figures 5 through 8 display the Range control charts for micronaire, strength, length and uniformity, respectively. An instrument's Range chart was determined to be in a state of statistical control for strength if not more than one point on the chart violated any of the above four decision rules. However, because of the discrete nature of the measurements of micronaire, length and uniformity, an instrument's Range chart was determined to be in a state of statistical control for these fiber properties if not more than one point violated rules 1 and 4, with rules 2 and 3 ignored. An instrument was determined to be operating in a state of statistical control for a fiber property if both the X-Bar and Range control charts were determined to be in control.

Table 1 shows the percentages of instruments tested in 1994 and 1995 that were determined to be operating in a state of statistical control. For all fiber properties, the percentage of in-control instruments decreased in 1995, with the decreases ranging from 5 percent for length to 15 percent for uniformity. Strength percentages decreased 7 percent and micronaire 12 percent. This warrants some concern. However, due to the limited number of years being compared and the small sample sizes for both years, some fluctuation in the number of out-of-control instruments is to be expected. It is important to remember that percentages can exaggerate these fluctuations.

Standard Deviations and Process Capabilities

The pooled process standard deviations from all in-control instruments for 1994 and 1995 are displayed in table 2 by fiber property. The micronaire standard deviation was the same for both years at 0.068. The other three fiber properties showed small decreases in the standard deviations, but none of the decreases were statistically significant; however, the decrease for strength could be considered practically different. The lack of significant and practical differences in standard deviations for micronaire, length and uniformity is expected as the instruments are the same model type from different production years. This leads to the conclusion that these standard deviations are good, unbiased estimators of the true process parameter for these measurements. The practical difference in the strength standard deviation is unexpected. The process parameter is most likely best estimated by pooling the strength standard deviations because these values are not significantly different. However, the possibility of an actual reduction in the process parameter cannot be ruled out because sample sizes were limited and rather small. Further testing of the instruments of this model type must be done before a good, unbiased estimator of the process parameter can be obtained.

It must be noted that the pooled standard deviations are estimators of the process standard deviation for this model, not for individual instruments. This is evidenced by slight increases in the C_p indices calculated using the pooled standard deviations and those calculated by averaging the indices computed for each instrument for both years(0.040 and 0.135 for micronaire; 0.017 and 0.028 for strength; 0.014 and 0.048 for length; and 0.013 and 0.041 for uniformity for 1994 and 1995, respectively). These differences result from pooling a few standard deviations that are significantly different from the majority. While it is not statistically valid to pool significantly different standard deviations, the authors believe that including all statistics from in-control instruments gives a better estimator of the process parameter because these represent valid measurements of the variability in the process as it presently operates.

Table 3 shows the process capabilities of in-control instruments for 1994 and 1995 by fiber property. Process capabilities are calculated by multiplying the standard deviation times six to establish the $\pm 3\sigma$ range. As with the standard deviations, only strength had an appreciable decrease from 1994 to 1995. Again, since the instruments in both years are the same model, the lack of differences is expected and the appreciable difference in the strength process capability unexplained. As stated regarding the standard deviations from which the process capabilities are calculated, the process capabilities for micronaire, length and uniformity are considered good, unbiased estimators of the process parameter. To obtain an equally good and unbiased estimate of the parameter for strength process capability would require further testing.

C_p and C_{pk} Indices

The average C_p indices for all in-control instruments for 1994 and 1995 are displayed by fiber property in table 4. Average C_p indices for all fiber properties increased from 1994 to 1995; however, only strength showed an appreciable increase. Average micronaire, length and uniformity indices remained in the marginal range (1.216 and 1.311; 1.148 and 1.244; and 1.132 and 1.268 for 1994 and 1995, respectively) while the average strength index increased into the acceptable range from 1.136 to 1.399 for 1994 and 1995, respectively.

The C_p indices associated with individual instruments showed more significant improvements. For micronaire, the number of instruments with unacceptable indices dropped from 20 percent to 10 percent. Fifty three percent of the 1994 instruments had marginal indices for micronaire and 27 percent had acceptable indices. In 1995, the number of marginal micronaire C_p indices dropped to 50 percent and the percentage with acceptable indices increased to 40 percent. A similar trend was seen for the other fiber properties as well. The percentages of instruments with unacceptable, marginal and acceptable strength C_p indices for 1994 and 1995 were 17 percent and

0 percent; 30 and 25; and 53 and 75, respectively. For length, the percentages were 17 and 5 unacceptable; 66 and 65 marginal; and 17 and 30 acceptable for the 1994 and 1995, respectively. The percentages of uniformity indices also improved from 1994 to 1995 with 20 percent to 5 percent unacceptable; 47 percent to 50 percent marginal; and 33 percent to 45 percent acceptable, respectively.

The standard deviations of individual instrument C_p indices decreased from 1994 to 1995 for all fiber properties. These decreases were 0.369 to 0.0237 for micronaire, 0.238 to 0.171 for strength, 0.186 to 0.109 for length and 0.266 to 0.166 for uniformity for 1994 and 1995, respectively. The differences, with the exception of micronaire, are statistically significant. Though not significant, the micronaire difference represents an appreciable and practical difference.

Table 5 displays the average C_{pk} indices by fiber property for all in-control instruments from 1994 and 1995. Average C_{pk} indices for all fiber properties increased from 1994 to 1995, with micronaire, strength and length having appreciable increases. Average micronaire and strength indices advanced from the unacceptable level to the marginal level (0.876 and 1.061; and 0.739 and 1.185 for 1994 and 1995, respectively). The length C_{pk} index remained in the unacceptable range increasing from 0.752 in 1994 to 0.994 in 1995. The uniformity C_{pk} index remained marginal with values of 1.010 for 1994 and 1.034 for 1995.

As with the C_p indices, there was even greater improvement in the C_{pk} indices of individual instruments than seen in the averages. For micronaire, the number of instruments with unacceptable indices dropped from 57 percent to 45 percent. Thirty six percent of the 1994 instruments had marginal indices for micronaire and 7 percent had acceptable indices. In 1995, the number of marginal micronaire C_{pk} indices increased to 40 percent and the percentage with acceptable indices increased to 15 percent. A similar trend was seen for the other fiber properties as well. The percentages of instruments with unacceptable, marginal and acceptable strength C_{pk} indices for 1994 and 1995 were 27 percent and 15 percent; 63 and 60; and 10 and 25, respectively. For length, the percentages were 67 and 40 unacceptable; 33 and 60 marginal; and 0 and 0 acceptable for the two years. The percentages of uniformity indices also improved from 1994 to 1995 with 58 to 40 percent unacceptable; and 42 to 60 percent marginal, with no instruments having acceptable C_{pk} indices in either year.

As with the standard deviations of the C_p indices, the standard deviations of individual instrument C_{pk} indices also decreased from 1994 to 1995 for all fiber properties. For micronaire, the standard deviation declined from 0.319 in 1994 to 0.203 in 1995. Though not statistically significant, most likely due to small sample sizes, this is an appreciable and practical difference. The standard deviations of strength and length C_{pk} indices were significantly lower in 1995 than in 1994 at 0.210 and 0.364; and 0.148 and 0.254, respectively. For uniformity, the standard deviation of the C_{pk} indices decreased from 0.302 in 1994 to 0.178 in 1995. This represents an appreciable and practical difference, but is not statistically significant due to the small sample sizes.

The improvements in the percentages of instruments in each of the three C_p and C_{pk} indices levels coupled with the only limited increases in the averages of these indices indicates that the variability is declining between instruments regarding their capabilities as measured by this index. This is further demonstrated by the decrease in the standard deviations of the C_p and C_{pk} values of individual instruments from 1994 to 1995. The declining variability between instruments and between calibrations evidences greater consistency to the fiber property measurement process. This most likely accounts for the slightly lower standard deviations and process capabilities and the higher C_p and C_{pk} indices.

C_{pk}/C_p Ratio

The ratios of the average C_{pk} index divided by the average C_p index are shown by fiber property in table 6. This ratio shows the percentage of the tolerance range that is included in Mean - NTL x 2 and indicates the effectiveness of calibration. If the process was perfectly centered such that the Mean equaled the target value, the ratio would be 1.000 (in this case, the two indices would be equal). Micronaire, strength and length showed an increase in this ratio from 1994 to 1995 (0.720 and 0.809 for micronaire, 0.651 and 0.847 for strength and 0.655 and 0.799 for length, respectively). The increases for strength and length were appreciable, but the increase for micronaire was not. Micronaire and strength were marginal, with length being at the upper limit of the unacceptable range. The ratio for uniformity decreased from 0.892 in 1994 to 0.804 in 1995 and was in the marginal range for both years. The increase in the micronaire ratio, while not appreciable, probably evidences an actual improvement in the effectiveness of calibration for this fiber property as well. The appreciable increases in the strength and length ratios indicate that calibration effectiveness is improving for these fiber properties, especially considering the higher C_p indices for 1995. The decrease in the uniformity ratio is due to a greater increase from 1994 to 1995 in the C_p index as opposed to the C_{pk} index. While the decrease should not be seen as negative for this reason, the ratio for this fiber property should be closely watched in the future as reductions in variability must be accompanied by improvements in calibration in order to continue improving both precision (reduced variability) and accuracy (correct calibration).

Summary

The capability of the Zellweger HVI model 900-Automatic with dual color heads to measure the cotton fiber properties of micronaire, strength, length and uniformity improved from 1994 to 1995. Though the percentage of instruments operating in statistical control declined over the two years, this is not viewed as a serious problem at this time because of the small sample sizes, but warrants watching in the future to ensure this is not a developing trend. Little or no decreases were seen in the standard deviations of these fiber properties, with the exception of strength which had an appreciable, but not statistically significant, decrease in the standard deviation from 1994 to 1995. However, even without reducing measurement variability, the average C_p and average C_{pk} indices increased for all measurements, as did the percentage of instruments in the marginal and acceptable index categories. This is explained by a greater consistency between instruments which is further evidenced by decreased standard deviations in the C_p and C_{pk} indices of individual instruments. The ratio of the C_{pk} index to the C_p index improved for all fiber properties except uniformity. This indicates that calibration is better centering the process at the correct level.

References

Lewicki, Garry L., Faia, Genna R., Fairley, Mary H. And Robles, Benjamin H. “High Volume Instrument Process Capability: A Comparison of 1991 through Current Levels.” *1995 Proceedings Beltwide Cotton Conference*, Quality Measurements Conference. National Cotton Council, Memphis, TN, pp. 1285-1289.

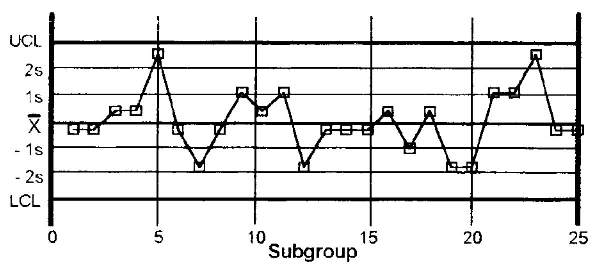

Figure 1. Micronaire X-Bar Control Chart

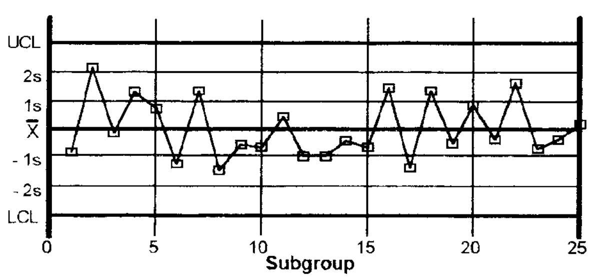

Figure 2. Strength X-Bar Control Chart

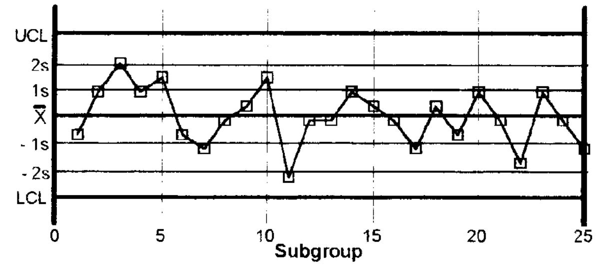

Figure 3. Length X-Bar Control Chart

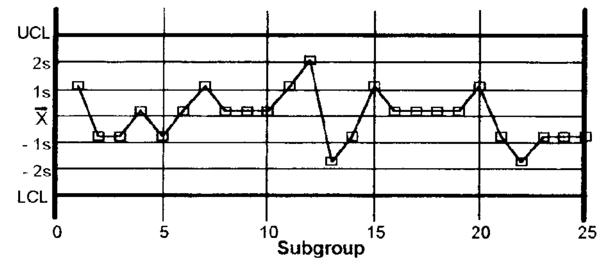

Figure 4. Uniformity X-Bar Control Chart

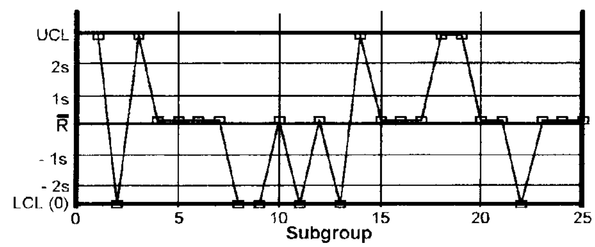

Figure 5. Micronaire Range Control Chart

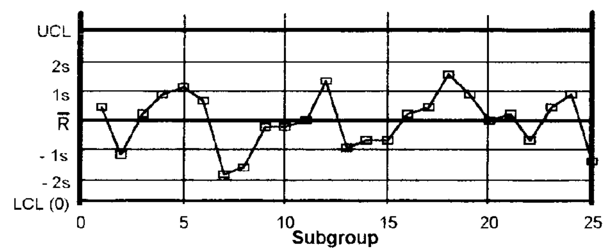

Figure 6. Strength Range Control Chart

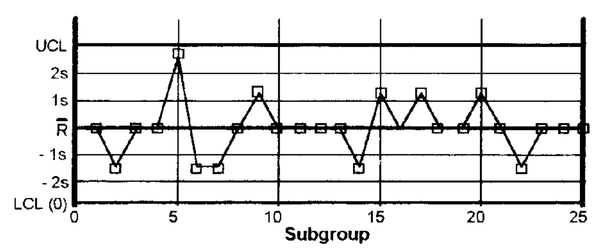

Figure 7. Length Range Control Chart

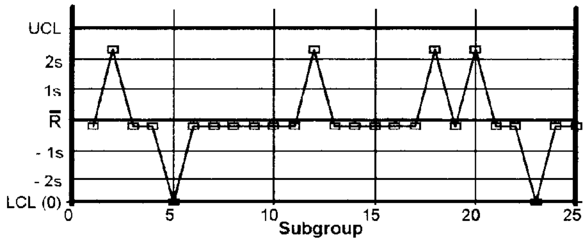

Figure 8. Uniformity Range Control Chart

Table 1. Percentages of HVI's In-Control for 1994 and 1995

	Mic.	Str.	Len.	Unif.
1994	97	97	100	100
1995	85	90	95	85

Table 2. Standard Deviations of In-Control HVI's for 1994 and 1995

	Mic.	Str.	Len.	Unif.
1994	0.068	0.745	0.0097	0.536
1995	0.068	0.608	0.0092	0.489

Table 3. Process Capabilities of In-Control HVI's for 1994 and 1995

	Mic.	Str.	Len.	Unif.
1994	0.408	4.470	0.0582	3.216
1995	0.408	3.648	0.0552	2.934

Table 4. Average Cp Indices of In-Control HVI's for 1994 and 1995

	Mic.	Str.	Len.	Unif.
1994	1.216	1.136	1.148	1.132
1995	1.311	1.399	1.244	1.268

Table 5. Cpk Indices of In-Control HVI's for 1994 and 1995 Computed by Instrument

	Mic.	Str.	Len.	Unif.
1994	0.876	0.739	0.752	1.010
1995	1.061	1.185	0.994	1.034

Table 6. Average Cpk Index /Average Cp Index Ratios of In-Control HVI's for 1994 and 1995

	Mic.	Str.	Len.	Unif.
1994	0.720	0.651	0.655	0.892
1995	0.809	0.847	0.799	0.804